CECW-EH Engineer Pamphlet 1110-2-11	Department of the Army U.S. Army Corps of Engineers Washington, DC 20314-1000	EP 1110-2-11 30 November 1994
	Engineering and Design ICE JAM FLOODING: CAUSES AND POSSIBLE SOLUTIONS	
	Distribution Restriction Statement Approved for public release; distribution is unlimited.	

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

EP 1110-2-11

CECW-EH

Pamphlet
No. 1110-2-11

30 November 1994

Engineering and Design
ICE JAM FLOODING: CAUSES AND POSSIBLE SOLUTIONS

1. Purpose

This pamphlet disseminates the results of research conducted by the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory on the causes and possible solutions to ice jam flooding problems.

2. Applicability

This pamphlet applies to all HQUSACE elements, major subordinate commands, districts, laboratories, and field operating activities having civil works responsibilities concerning ice.

3. References

(See Appendix A.)

4. General

In spite of significant annual damages, ice jam flooding has received little public attention. This document brings together the diverse technical and nontechnical information that comprises the state of the art in ice jam mitigation. These concepts, which are based on the extensive experience, should be considered for new or rehabilitation projects where applicable.

FOR THE COMMANDER:

R. L. VANANTWERP
Colonel, Corps of Engineers
Chief of Staff

DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

EP 1110-2-11

CECW-EH

Pamphlet
No. 1110-2-11

30 November 1994

Engineering and Design
ICE JAM FLOODING:
CAUSES AND POSSIBLE SOLUTIONS

Table of Contents

Chapter 1
Introduction

1-1. Purpose

This pamphlet provides the diverse technical and nontechnical information that comprises the state of the art in ice jam mitigation.

1-2. Applicability

This pamphlet is applicable to all HQUSACE elements, major subordinate commands, districts, laboratories, and field operating activities located in the freezing zone with responsibility for design, construction, and operation.

1-3. References

A list of references is included as Appendix A.

1-4. Audience

The information is intended to be helpful to hydraulic engineering specialists and emergency operations personnel as well as state and local officials who are responsible for rapid, effective response to ice jam emergencies.

1-5. Explanation of Terms

See Appendix B for a glossary of terms.

Chapter 2
Problem

2-1. Flooding in the United States

a. Flooding and flood-related events cause greater damage and more fatalities than any other natural disaster. About 80 percent of all presidential disaster declarations are the result of flooding (Federal Emergency Management Agency (FEMA) 1992a). Flood damages averaged $3.3 billion and flood-related fatalities averaged about 100 annually over the past 10 years (USACE 1993, 1994). The most common type of flood occurs as a result of a major rainfall or snowmelt. A second type of flood occurs suddenly, as in the case of dam failures or intense rainfall that generates a flash flood. A third category of flood results from an ice or debris jam. Flood stages during an ice jam (Figure 2-1) can increase more rapidly and attain higher levels than those associated with open water conditions. Ice jam flooding may occur outside the regulatory floodplain, often when the river flow would not otherwise cause problems.

b. Many laws and regulations have been developed to reduce national vulnerability to flooding. Most American communities have floodplain regulations designed to prevent future development in areas subject to conventional open water flooding. Some communities are protected by structural controls such as dikes, levees, and flood control dams. Mitigation measures specifically designed to protect against ice jam flooding are used less commonly.

2-2. Ice Jam Flooding

a. In many northern regions ice covers the rivers and lakes annually. The annual freezeup and breakup commonly occur without major flooding. However, some communities face serious ice jam threats every year, while others experience ice-jam-induced flooding at random intervals. The former often have developed emergency plans to deal with ice jam problems, but the latter are often ill-prepared to cope with a jam event when it occurs.

b. Ice jams take place in 30 states, primarily in the northern tier of the United States (Figure 2-2). Even mountainous regions as far south as New Mexico and Arizona experience river ice. Ice jams affect the major navigable inland waterways of the United States including the Great Lakes. A study conducted in Maine, New Hampshire, and Vermont identified over 200 small towns and cities that reported ice jam flooding over a 10-year period (USACE 1980). In March 1992 alone, 62 towns in New Hampshire and Vermont reported ice jam flooding problems after two rainfall events. Table 2-1 lists some of the major ice jams recently recorded.

c. In a l992 survey, USACE offices reported ice jam problems within 36 states. Of the 36 states, 63 percent reported that ice jams occur frequently, and 75 percent rated ice jams as being serious to very serious (White 1992).

d. Because ice jam events are less common and more poorly documented than open water events, it is more difficult to characterize these events than open water flooding. In addition, due to the complex processes involved in the formation and progression of ice jams and the highly site-specific nature of these jams, these events are more difficult to predict than open water flooding.

e. The rates of water level rise can vary from feet per minute to feet per hour during ice jam flooding. In some instances, communities have many hours of lead time between the time an ice jam forms and the start of flooding. In other cases, the lead time is a little as one hour. For example, in March 1992, an ice jam developed at 7:00 a.m. in Montpelier, VT. By 8:00 a.m. the downtown area was flooded (Figure 2-3). During the next 11 hours, the business district was covered with an average of 1.2 to 1.5 m (4 to 5 ft) of water. The event occurred so quickly that there was not sufficient time to warn residents so they could protect their goods. Even after water levels dropped, damage related to the flooding continued as cold temperatures caused freezeup of wet objects. Damages of less than one day were estimated at $5 million (FEMA 1992b).

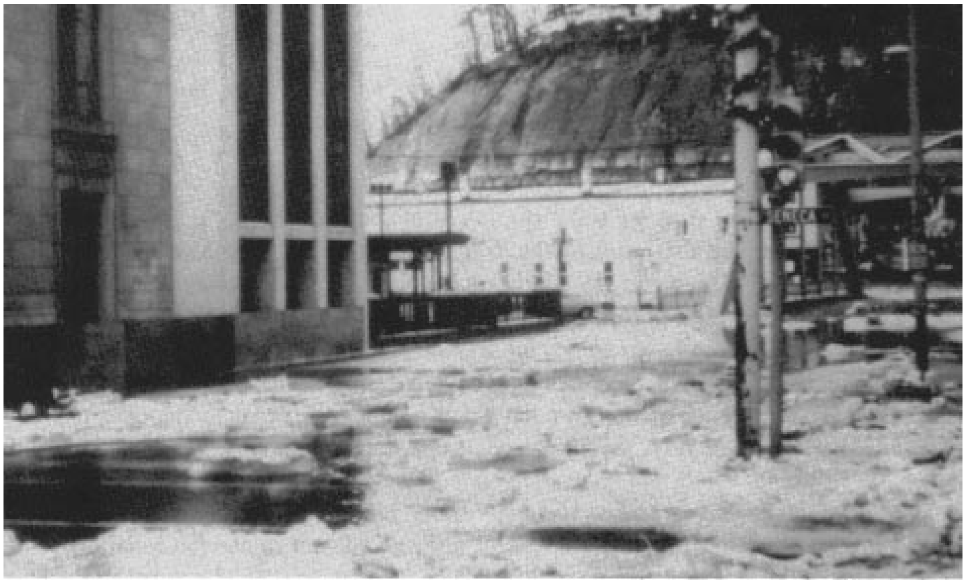


Figure 2-1. Ice jam flooding

f. Although the actual time period of flooding may be short compared to open water flood events lasting days to weeks, significant damage can result. The winter weather conditions often prevalent when ice jams occur also add to the risks and damages associated with ice jam flooding.

2-3. Ice Jam Flood Losses

a. Ice jam flooding is responsible for loss of life, although the number of fatalities in the United States is considerably less than non-ice jam flooding. In the last 30 years at least seven people have died as a result of ice jam flooding. Six of the deaths were attributed to rescue attempts; the other death occurred from injuries sustained when a basement wall collapsed due to pressure from flood waters and ice.

b. Ice jams in the United States cause approximately $125 million in damages annually, including an estimated $50 million in personal property damage and $25 million in operation and maintenance costs to USACE navigation, flood control, and channel stabilization structures.

c. Ice jams suspended or delayed commercial navigation causing adverse economic impacts (Figure 2-4). Although navigational delays are commonly short, they may result in shortages of critical supplies, such as coal and industrial feedstocks and large costs from the operation of idle vessels (USACE 1981). Ice jams sometimes cause damage to navigation lock gates. For more detailed information on the effects ice jams have on navigation and the range of strategies to mitigate the effects, see “Winter Navigation on Inland Waterways” (USACE 1990).

d. Ice jams also affect hydropower operations, causing suspension of hydropower generation due to intake blockage, high tailwater, the necessity to reduce discharge, or damage to intake works (Figure 2-5). Lost power revenue due to such shutdowns can be substantial.

e. The presence of an ice jam can result in scouring and river bed and bank erosion that may lead to bridge or river bank failure (Figure 2-6). Ice jams can damage stream channels and improvements so that overall vulnerability to flooding is increased. Riprap can be undermined or moved out of place. Ice-jam-related damage to river training structures costs millions of dollars each year.

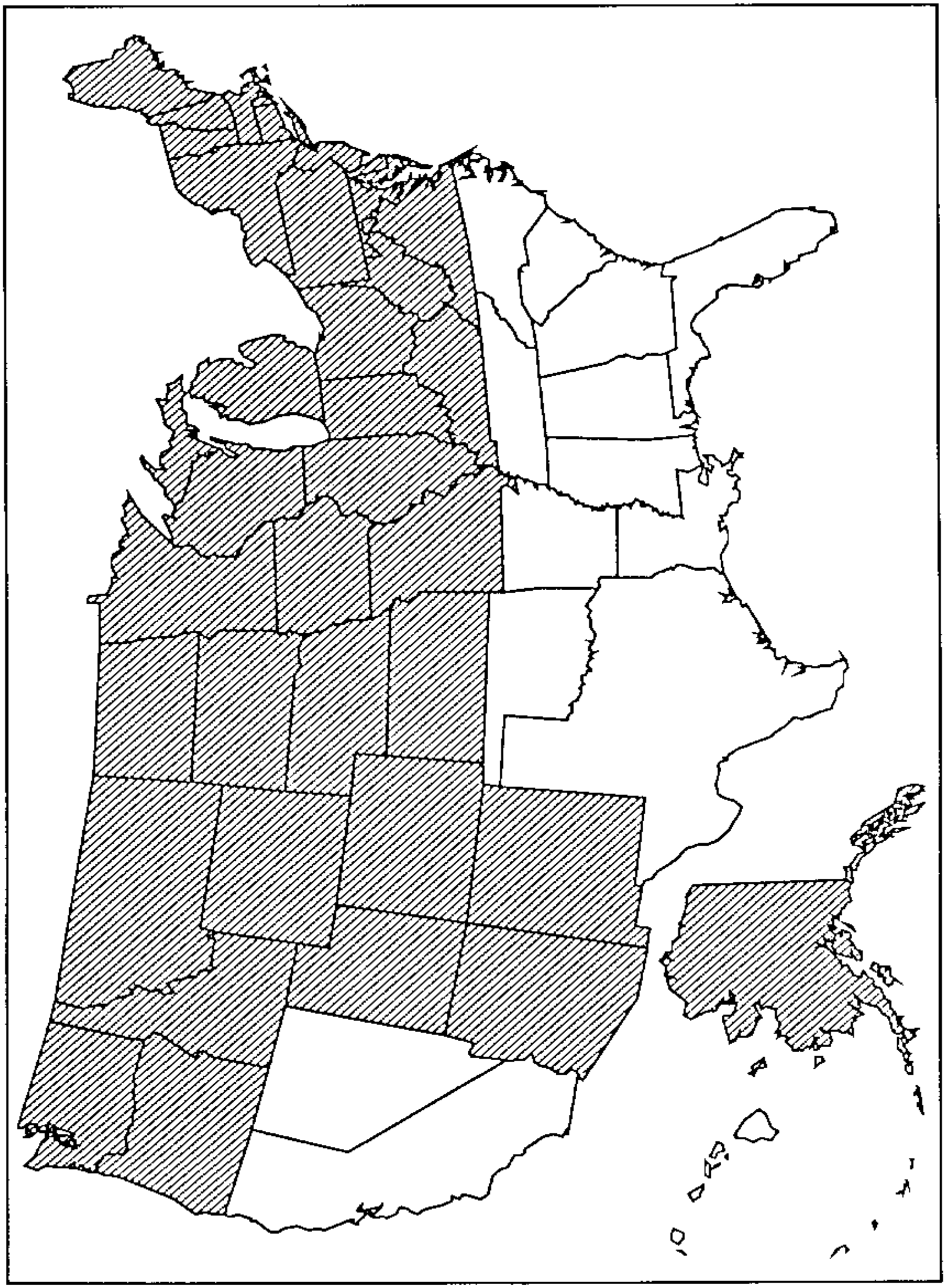


Figure 2-2. Ice jam flooding occurs in shaded states

Table 2-1
Recent Major Ice Jams in the United States

Place	Date	Type (Damages)
Montpelier, VT	March 1992	Breakup ($5M)
Allagash, ME	April 1991	Breakup ($14M)
Salmon, ID	February 1984	Freezeup ($1.8M)
Port Jervis, NY Matamoras, PA	February 1981	Breakup ($14.5M)
Mississippi/Missouri Rivers confluence	December 1989	Breakup (>$20M)

f. Indirect costs associated with ice jams include loss of fish and wildlife and their habitat. Scour and erosion associated with ice jams may destroy habitat, such as eagle roosting trees, and mobilize toxic materials buried in sediment. Some scouring may, however, be beneficial to wildlife habitat as well. Shallow, vegetation-choked wetlands may become open, allowing for fish and waterfowl spawning and brood habitat.

a. Winooski River

b. Downtown area

Figure 2-3. Views of Montpelier, VT, ice jam (March 1992)

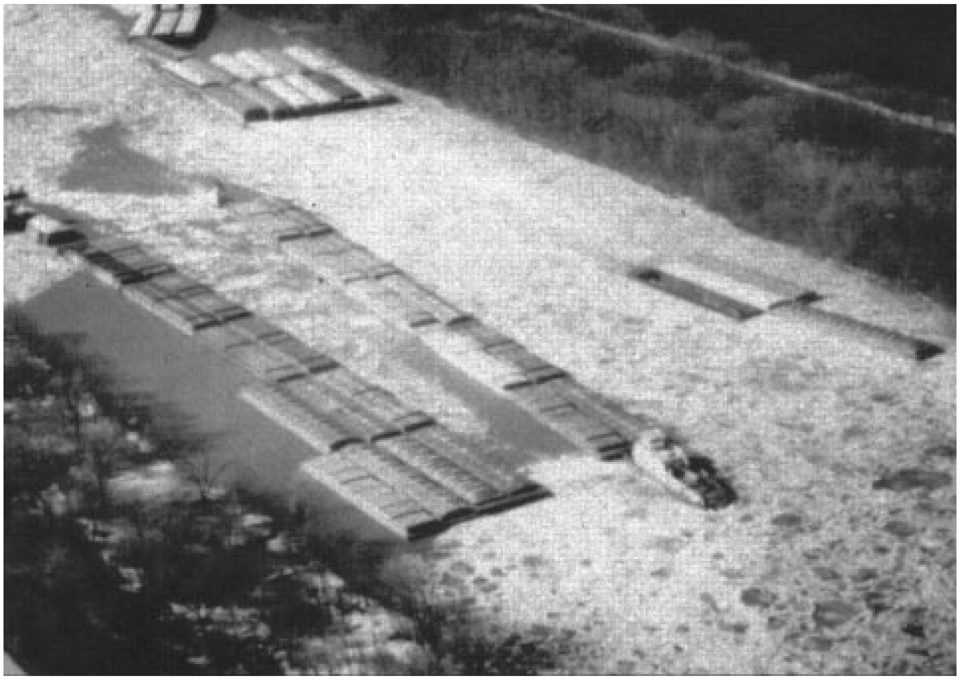


Figure 2-4. Towboats and barges in ice

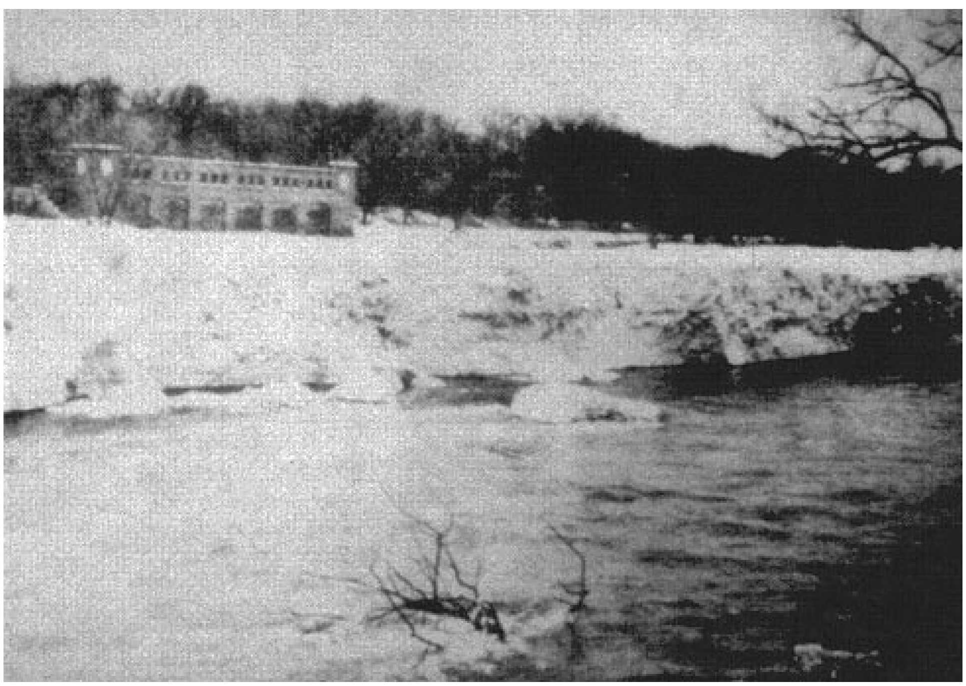


Figure 2-5. Jam immediately downstream of power plant, Fox River, IL

Figure 2-6. Bank scour due to a breakup jam, St. John River, MN, near Allagash

Chapter 3
Background

3-1. Types of Ice

a. Ice forms in freshwater bodies whenever the surface water cools to 0 ºC (32 ºF) or a fraction of a degree lower. There are many types of ice, depending on the precise mode of formation and evolution (Ashton 1986).

b. *Sheet ice* forms in calm water, such as lakes or reservoirs, or in slow-moving river reaches where the flow velocity is less than 0.5 m/s (1.5 ft/s). Ice crystals formed at the water surface freeze together into skim ice that gradually thickens downward as heat is transferred from the water to the air through the ice layer. Sheet ice usually originates first along the banks and expands toward the center of the waterbody. In slow rivers, the sheet ice cover may also be created by the juxtaposition of incoming frazil pans generated in upstream faster reaches. Sheet ice that grows statically in place is often called *black ice* because of its appearance. An ice cover may also thicken at the top surface when water-soaked snow freezes to form *snow ice* that has a milky white appearance.

c. *Frazil ice* (Figure 3-1) consists of small particles of ice formed in highly turbulent, supercooled water, such as river rapids or riffles, during cold, clear winter nights when the heat loss from the water to the atmosphere is very high. As the frazil particles are transported downstream, they join together to form flocs that eventually rise to the surface where they form frazil pans or floes. Frazil is often described as *slush ice* because of its appearance.

d. *Fragmented ice* is made up of ice pieces that originated as consolidated frazil ice pans or from the breakup of sheet ice growing at the surface of slow-moving water.

e. *Brash ice* is an accumulation of ice pieces less than 1.5 to 2 m (5 to 6 ft) in maximum dimension resulting from the breakup of an ice cover by increasing water flow or by vessel passage. It is of particular concern in navigation channels and lock approaches.

3-2. Types of Ice Jams

a. An ice jam is a stationary accumulation of ice that restricts flow. Ice jams can cause considerable increases in upstream water levels, while at the same time downstream water levels may drop, exposing water intakes for power plants or municipal water supplies. Types of ice jams include freezeup jams, made primarily of frazil ice; breakup jams, made primarily of fragmented ice pieces; and combinations of both.

b. *Freezeup jams*. Freezeup jams are composed primarily of frazil ice, with some fragmented ice included, and occur during early winter to midwinter. The floating frazil may slow or stop due to a change in water slope from steep to mild because it reaches an obstruction to movement such as a sheet ice cover, or because some other hydraulic occurrence slows the movement of the frazil (Figure 3-2). Jams are formed when floating frazil ice stops moving downstream, forms an “arch” across the river channel, and begins to accumulate. Freezeup jams are characterized by low air and water temperatures, fairly steady water and ice discharges, and a consolidated top layer.

c. *Breakup jams*. Breakup jams occur during periods of thaw, generally in late winter and early spring, and are composed primarily of fragmented ice formed by the breakup of an ice cover or freezeup jam (Figure 3-3). The ice cover breakup is usually associated with a rapid increase in runoff and corresponding river discharge due to a significant rainfall event or snowmelt. Late season breakup is often accelerated by increased air temperatures and solar radiation.

d. The broken, fragmented ice pieces move downstream until they encounter a strong, intact downstream ice cover or other surface obstruction to flow, or other adverse hydraulic conditions such as a significant reduction in water surface slope. Once they reach such a jam initiation point, the fragmented ice pieces stop moving, begin to accumulate, and form a jam (Figure 3-4). The ultimate size of the jam (i.e., its length and thickness) and the severity of the resulting

Figure 3-1. Frazil ice and frazil pans (Salmon River, ID)

Figure 3-2. Frazil pans slowing down, being compressed, and breaking off in arch shape. They will eventually stop (flow is from left to right)

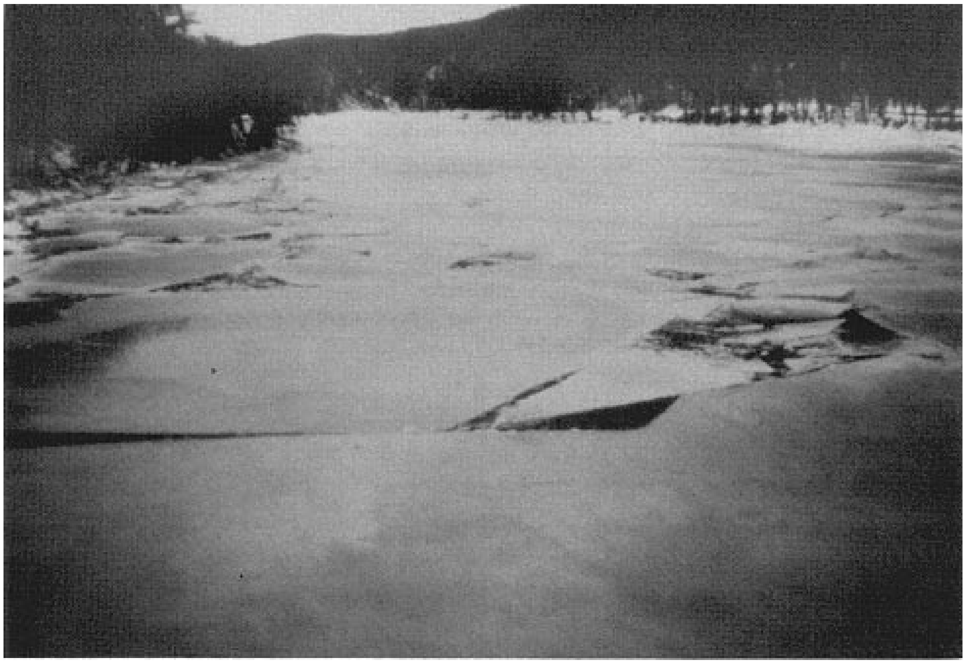


Figure 3-3. Initial breakup of sheet ice

Figure 3-4. Breakup jam

flooding depend on the flow conditions, the available ice supply from the upstream reaches of the river, and the strength and size of the ice pieces.

e. Midwinter thaw periods marked by flow increases may cause a minor breakup jam. As cold weather resumes, the river flow subsides to normal winter level and the jammed ice drops with the water level. The jam may become grounded as well as consolidated or frozen in place. During normal spring breakup, this location is likely to be the site of a severe jam.

f. *Combination jams*. Combination jams involve both freezeup and breakup jams. For example, a small freezeup jam forms in a location that causes no immediate damage. Before the thaw, the jam may provide a collecting point for fragmented ice that floats downstream. On the other hand, it could break up at the same time as the remainder of the river. Since the jam is usually much thicker than sheet ice, it significantly increases the volume of ice available to jam downstream.

g. In some rivers, frazil ice does not cause freezeup jams; instead, it deposits beneath sheet ice in reaches of slow water velocities. These frazil ice deposits, called hanging dams, are many times thicker than the surrounding sheet ice growth and will tend to break up more slowly than thinner ice. Such a frazil deposit could also provide an initiation point for a later breakup jam, as well as increase the volume of ice available to jam downstream.

3-3. Causes of Ice Jams

a. River geometries, weather characteristics, and floodplain land-use practices contribute to the ice jam flooding threat at a particular location.

b. Ice jams initiate at a location in the river where the ice transport capacity or ice conveyance of the river is exceeded by the ice transported to that location by the river's flow. The most common location is in an area where the river slope changes from relatively steep to mild. Since gravity is the driving force for an ice run, when the ice reaches the milder slope it loses its impetus and can stall or arch across the river and initiate an ice jam. Water levels in reservoirs often affect the locations of ice jams upstream as a result of a change in water slope where reservoir water backs up into the river. Islands, sandbars, and gravel deposits often form at a change in water slope for the same reasons that ice tends to slow and stop. Because such deposits form in areas propitious to ice jamming, they are often mistakenly identified as the cause of ice jams. While these deposits may affect the river hydraulics enough to cause or exacerbate an ice jam, the presence of gravel deposits is usually an indication that the transport capacity of the river is reduced for both ice and sediment. Ice jams located near gravel deposits should be carefully studied to determine whether the gravel deposit is the cause of the jam or a symptom of the actual cause.

c. Ice jams also commonly form where a tributary stream enters a larger river, lake, or reservoir. Smaller rivers normally respond to increased runoff more quickly than larger rivers, and their ice covers may break up sooner as a result of more rapid increases in water stage. Ice covers on smaller rivers will typically break up and run until the broken ice reaches the strong, intact ice cover on the larger river or lake, where the slope is generally milder. The ice run stalls at the confluence, forming a jam and backing up water and ice on the tributary stream.

d. River bends are also frequently cited as ice jam instigators. While river bends may contribute to jamming by forcing the moving ice to change its direction and by causing the ice to impact the outer shoreline, water slope is often a factor in these jams as well (Wuebben, Gagnon, and Deck 1992, Urroz and Ettema 1994).

e. Obstructions to ice movement can cause ice jams, for example closely spaced bridge or dam piers. In high runoff situations, a partially submerged bridge superstructure obstructs ice movement and may initiate a jam. In smaller rivers trees along the bank sometimes fall across the river causing an ice jam.

f. Some structural or operational changes in reservoir regulation may lead to ice jams. For example, changes in hydropower operations can inadvertently cause ice jam flooding. Sudden releases of water such as those characteristic of peaking plants may initiate ice breakup and subsequent jamming. On the other hand, wise reservoir regulation during freezeup or breakup periods can reduce ice jam flood risks.

g. Removing or building a dam may cause problems. In many parts of the country, small dams that once functioned for hydropower have fallen into disrepair. Communities may remove them as part of a beautification scheme or to improve fish habitat. However, the effects of an existing dam on ice conditions should be considered before removing or substantially altering an existing dam. It is possible that the old dams provide ice control by delaying ice breakup or providing storage for ice debris. Dam construction can also affect ice conditions in a river by creating a jam initiation point. On the other hand, the presence of a dam and its pool may be beneficial if frazil ice production and transport decrease as a result of ice cover growth on the pool.

Chapter 4
Ice Jam Mitigation Techniques

4-1. Ice Jam Flood Control

a. Until the 1970s, flood control concentrated largely on open water flood events and was considered primarily a Federal responsibility. Large structural solutions such as levees or flood control dams were built. Now the Federal government requires local and state governments to share the costs, and government policies favor small-scale, locally funded projects. In light of significantly reduced budgets, innovative ice jam mitigation techniques that require low maintenance and low up-front costs, have low environmental impacts, and yield excellent results in terms of reduced flooding damages are being developed. Many of these are appropriate for design and implementation in smaller cities and towns.

b. In 1990 FEMA initiated the Community Rating System to reward local hazard mitigation efforts by reducing flood insurance premiums in communities that adopt relocation, hazard area acquisition, and other mitigation policies. "Clearly, Federal flood hazard policy is demonstrating an increasing emphasis on mitigation... Mitigation works to change the nature of the threat, decreases vulnerability to damage and reduces exposure to the hazard" (Drabek and Hoetmer 1991).

c. A number of ice jam flood mitigation measures are possible (USACE 1982). These measures can be of a structural or nonstructural nature, appropriate to control breakup jams or freezeup jams. Some are permanent, some are deployed in advance of an anticipated flood threat, while others are deployed under emergency conditions when a jam has formed and flooding has occurred.

d. *Structural measures* for ice jam control may incorporate features that can be used to alleviate open water flooding as well as those designed specifically for ice jam flood events. The cost of such measures includes construction, operation, and land acquisition as well as costs associated with recreation and environmental mitigation. Unfortunately, while they are often very successful, structural solutions tend to be expensive. Structural solutions remain appropriate on rivers where chronic or serious threats persist and where the extent of potential damages justifies the cost. Although the majority of the structural mitigation techniques are, by their very nature, permanent, some are designed to be removable. These removable structures are usually installed at the beginning of winter and removed after spring breakup when the threat of ice jam flooding no longer exists. A few removable structures are designed to be deployed after an ice jam threat has been identified and, in this respect, can be considered advance mitigation measures.

e. *Nonstructural measures* are designed to modify vulnerability to the flood threat or to reduce the severity of the ice jam and of the resulting flood. They are generally less expensive than structural solutions. The majority of the nonstructural techniques are used for advance and emergency measures when serious ice jam flooding is imminent or under way. For example, if sufficient warning is provided, ice weakening (ice cutting or dusting) may be implemented before an ice jam occurs. Blasting and mechanical removal are often employed only as emergency mitigation measures once ice jams have occurred. The creation of ice storage zones upstream from a known jam site to minimize the amount of ice reaching the jam site is a permanent measure since these areas, once established and properly maintained, can be used year after year.

f. *Freezeup ice jam* control usually targets the production and transport of the frazil ice that causes jams. This may be accomplished by encouraging the growth of an ice cover that insulates the water beneath, decreasing the production of frazil ice. The ice cover collects and incorporates frazil ice that is transported from upstream. This reduces the amount of ice moving downstream.

g. *Breakup ice jam* control focuses on affecting the timing of the ice cover breakup, thereby reducing the severity of the resulting jam to the point where little or no flooding occurs, or on controlling the location of the ice jam by forcing the jam to occur in an area where flooding damages will be inconsequential.

h. Table 4-1 summarizes the currently available jam mitigation techniques and indicates whether they are applicable to freezeup or breakup jams and whether they are appropriate for permanent, advance, or emergency measures. In the

Table 4-1
Ice Jam Mitigation Methods

Technique	Jam Type	Type of Mitigation
Structural		
Dikes, levees, floodwalls	F, B	P
Dams and weirs	F, B	P
Ice booms	F, B	P, A
Retention structures	B	P
Channel modifications	F, B	P
Ice storage zones	B	P, A
Nonstructural		
Forecasting	F, B	A, P
Monitoring and detection	F, B	E, A, P
Thermal control	F, B	E, A, P
Land management	F, B	P
Ice cutting	B	A
Operational procedures	F, B	A, P
Dusting	F, B	E, A
Ice breaking	F, B	E, A
Mechanical removal	F, B	E, A
Blasting	F, B	E, A
Traditional Techniques		
Floodproofing	F, B	P
Sandbagging	F, B	A, E
Evacuation	F, B	A, E
Levee closing	F, B	A, E

Key: B = Breakup jam, F = Freezeup jam, P = Permanent measure,
A = Advance measure, E = Emergency measure

following sections, the ice jam mitigation methods are described in detail: first, those that are primarily permanent measures; second, those appropriate for advance measures; and third, those applicable to emergency situations. Traditional flood fighting methods, namely floodproofing, sandbagging, levee closing, or evacuation, are obviously applicable to ice jam floods. They are only briefly summarized under the pertinent sections.

i. The best mitigation strategy often combines structural and nonstructural measures, such as an ice boom associated with temporary modifications in the operation of an upstream water control dam, as well as permanent, advance, or emergency measures. Table 3 lists common ice jam mitigation strategies and corresponding techniques.

j. When an ice jam control program is developed following an ice jam flood event to prevent similar events from recurring, it is necessary to determine the type of jam, source of ice, local and remote causes of the jam, and meteorological and hydrological conditions that led to the jam formation. An ice jam data collection program, as described by White and Zufelt (1994) or Elhadi and Lockhart (1989), should be an integral part of an ice jam mitigation effort to address all of these points.

k. Data collection should not be limited to the immediate vicinity of the jam location. It is important to study upstream and downstream areas since the source of ice and the actual causes of ice jamming at a particular site may be far removed from the actual jam location. This data gathering phase of the program is critical to select the jam mitigation strategy and corresponding mitigation techniques best appropriate to the site under study.

l. Successful ice jam mitigation often requires multijurisdictional cooperation and interagency coordination. For example, a catastrophic breakup ice jam on the Delaware River in February 1981 affected three states and caused

Table 4-2
Ice Jam Mitigation Strategies and Applicable Techniques

Protect surrounding areas from flood damages
Dikes, levees, and floodwalls
Floodproofing
Floodplain land use management
Sandbagging
Levee closing
Evacuation
Reduce ice supply
Thermal control
Revised operational procedures
Ice booms
Dams and weirs
Ice storage zones
Dusting
Ice retention
Increase river ice and water conveyance
Channel modifications
Revised operational procedures
Control ice breakup sequence
Detection and prediction
Ice booms
Ice retention
Ice cutting
Ice breaking
Revised operational procedures
Displace ice jam initiation location
Dams and weirs
Ice piers, boulders, and cribs
Ice booms
Ice breaking
Channel modifications
Remove ice
Thermal control
Ice breaking
Mechanical removal
Blasting

$14.5 million in damages. After extensive collaboration between Federal and state agencies in New Jersey, Pennsylvania, and New York, a diversion channel was proposed to be built physically in New Jersey that also provided major flood loss reduction benefits to New York and Pennsylvania.

4-2. Permanent Measures

a. Dikes, levees, and floodwalls. Dikes, levees, and floodwalls physically separate the river from property to be protected. These measures protect against open water floods as well as ice jam floods. However, designs adequate for open water protection may not be adequate to handle ice jam stages that cause physical damage.

b. Dams and weirs.

(1) Dams are used to affect the thermal and flow regimes of a river. As breakup jam control structures, dams are designed to suppress or change the duration or timing of ice jam formation downstream by intercepting the solid ice

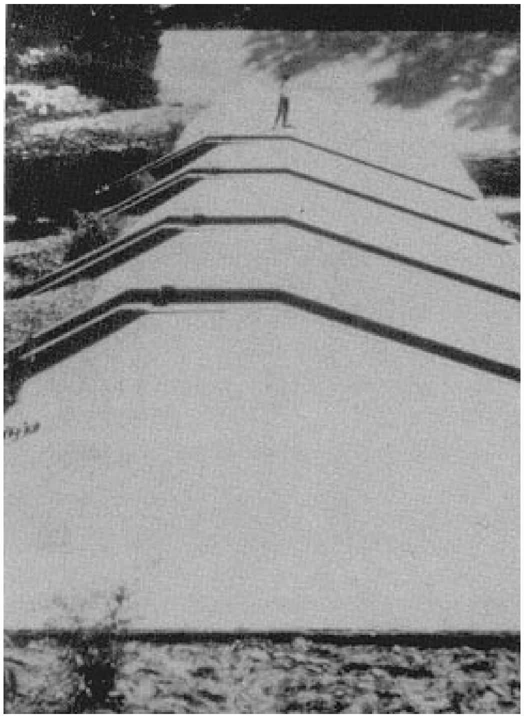


Figure 4-1. Lancaster, NH, structure

pieces incoming from upstream. For freezeup jam control, a dam promotes the formation of an upstream stable sheet ice cover in order to minimize the generation of frazil ice and the consequent formation of a freezeup jam.

(2) For example, gates may be designed to allow run-of-river flow during most of the year, but in the winter are closed at freezeup so rapids are inundated (Figure 4-1). This eliminates local frazil ice production, reduces the supply of frazil moving downstream, and slows the freezeup jam progression.

(3) A dam designed to reduce ice jam flooding can be part of a multiobjective community project where benefits for open water flood control, navigation, recreation, water supply, irrigation, or hydropower justify much of the construction costs.

(4) For smaller rivers, when financial or environmental constraints eliminate consideration of major structural works, relatively low-cost alternatives can still provide significant ice jam control. For freezeup control, a still-experimental fabric tension weir (Figure 4-2) supported by cables anchored at the banks may be an economically feasible alternative. For breakup control, a permeable, cable-supported wire mesh (similar to submarine net (Figure 4-3)) may be strung across the stream to temporarily hold ice from upstream while the downstream reaches of the stream are cleared of ice. These two types of structures are removable and can be seasonably deployed. However, they often require local bed and bank protection against scour for stability and effectiveness. Provisions to allow part of the flow to divert around the structures to limit the upstream flow depth may be required.

c. Ice booms.

(1) Ice booms are the most widely used type of ice control structure (Figure 4-4). They are a series of timbers or pontoons tethered together and strung across a river to control the movement of ice. Booms are flexible and can be designed to release ice gradually and partially when overloaded. Ice booms are relatively inexpensive and can be placed seasonally to reduce negative environmental impacts.

(2) Booms commonly stabilize or retain an ice cover in areas where surface flow velocities are 0.76 m/s (2.5 ft/s) or less and relatively steady. In some cases, a weir or small structure can improve hydraulic conditions at the ice boom location, especially on small, steep streams. Some booms are located at the outlets of lakes or reservoirs to keep ice from entering downstream ice-jam-prone reaches.

(3) Conventional ice booms may be used in breakup situations to hold back the ice for a brief time, allowing the initiation of emergency response measures such as evacuation or sandbagging. Booms can be placed to direct the movement of ice pieces away from an intake or navigation channel. Ice control booms are also used to promote ice cover formation during freezeup as part of freezeup ice jam mitigation efforts.

d. Ice retention.

(1) Ice retention structures control breakup jams by promoting the initiation of an ice jam at a suitable location where flooding will create little or no damage. Fragmented ice is captured and retained upstream from the retention structure to create the ice jam. Ice retention structures can range from suspended structures such as a submarine net or vertically oriented ice booms, to streambed structures such as concrete piers (Figure 4-5), large boulders, or rock-filled cribs placed at regular intervals across the width of the stream. Provision for a floodplain or diversion channel may also be required

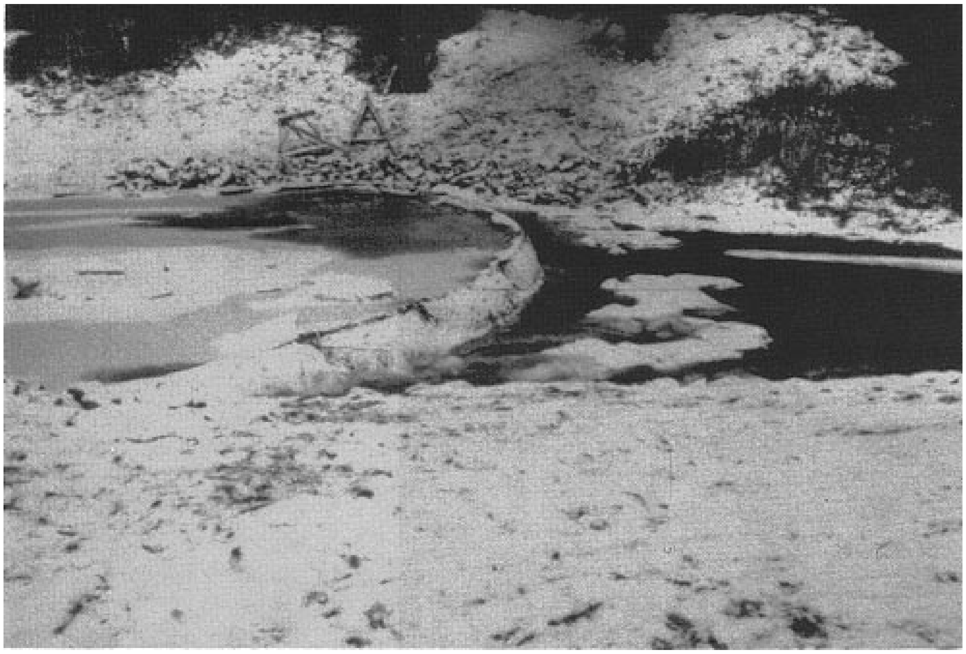


Figure 4-2. Tension weir

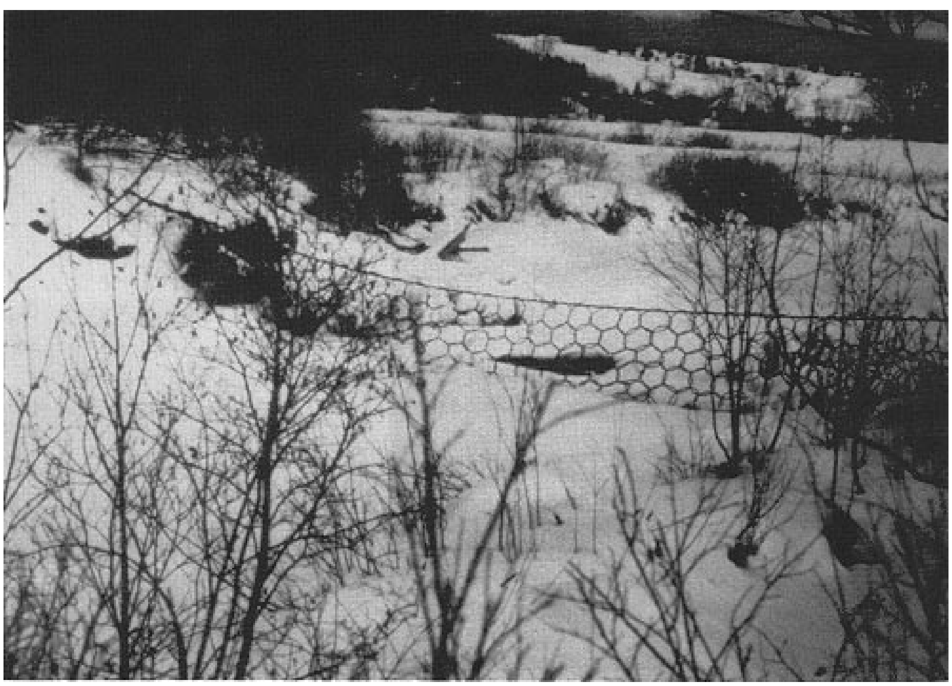
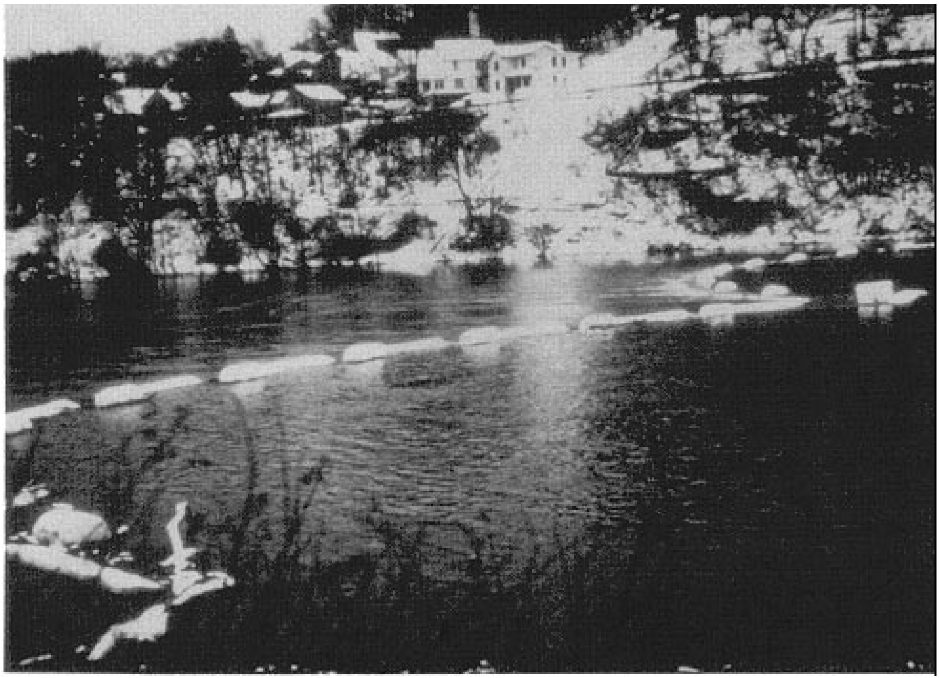
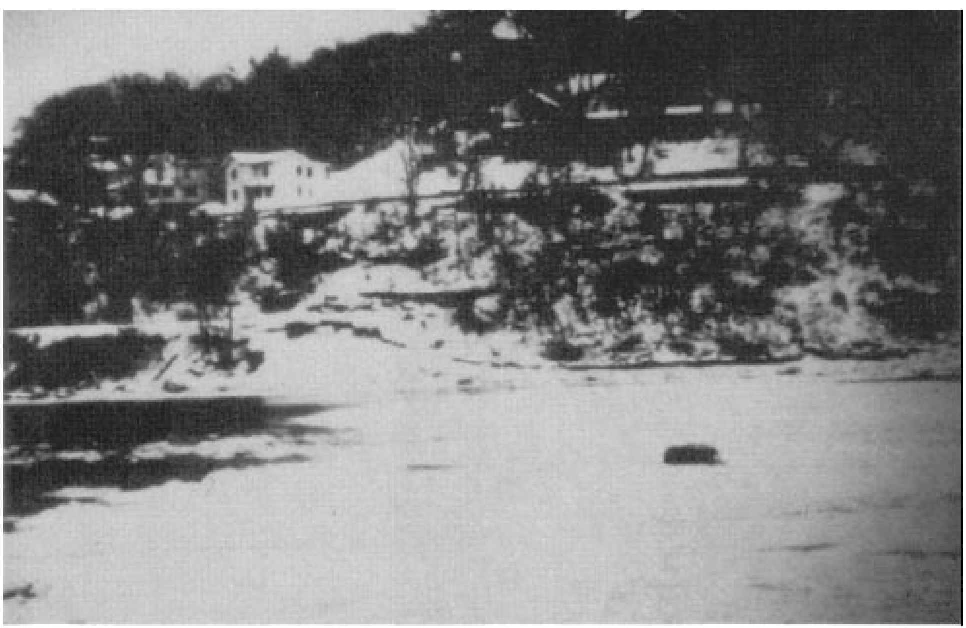


Figure 4-3. Submarine net



a. Prior to freezeup



b. After freezeup

Figure 4-4. Ice boom on Allegheny River near Oil City, PA

Figure 4-5. Ice piers for breakup control

to limit the rise in upstream water level and corresponding load on the structure elements as well as upstream flooding potential.

(2) Suspended structures may be placed seasonally, but require adequate permanent anchoring to withstand the ice forces. These structures are generally more suited to smaller rivers and streams. The size and anchoring of projecting structures such as piers, boulders, or cribs must be determined to withstand the anticipated ice forces, and their spacing is a function of the average ice floe size.

(3) This type of jam control does not block the entire river width but allows for recreational navigation and fish passage. Therefore, it can be installed permanently. The bed of the stream may need to be protected against scour around all elements of this type of structure to ensure that they remain stable.

e. Channel modifications.

(1) Modifications to the river channel can improve the passage of ice through reaches where ice jams tend to form, such as changes in slope, river bends, slow moving pools, and constrictions. Dredging or excavation can widen, deepen, or straighten the natural channel. Old bridge piers and natural islands and gravel bars can be removed.

(2) Diversions (Figure 4-6) can bypass ice and water flow around the normal jamming sites, lowering the upstream stage. When diversion channels are used, they should be designed to remain dry except during flood events so they will be available to function as open water channels and not contribute to the downstream ice supply.

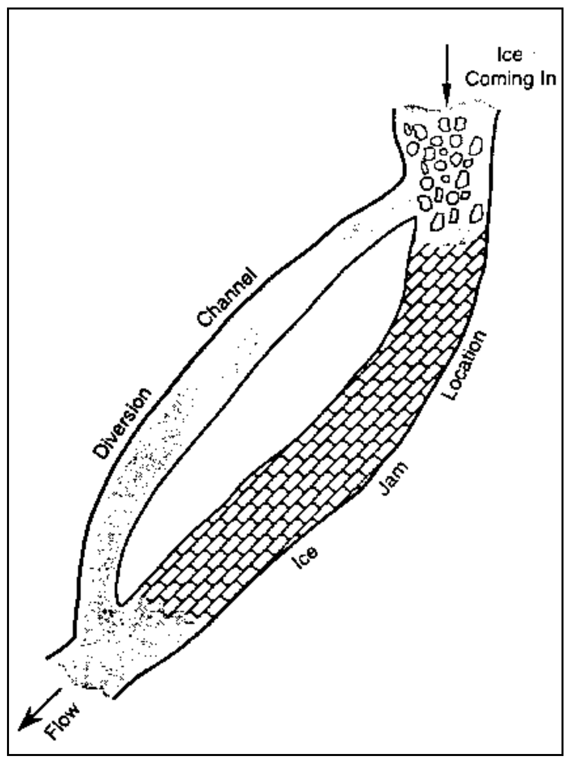


Figure 4-6. Schematic of diversion channel for ice jam flooding control

A diversion channel can improve performance of an ice control structure. If an ice control dam or weir is used to control a breakup ice run, an associated high-level diversion could be used to limit the discharge reaching the structure, reducing river stages to prevent local flooding and ensuring the stability of the ice being retained.

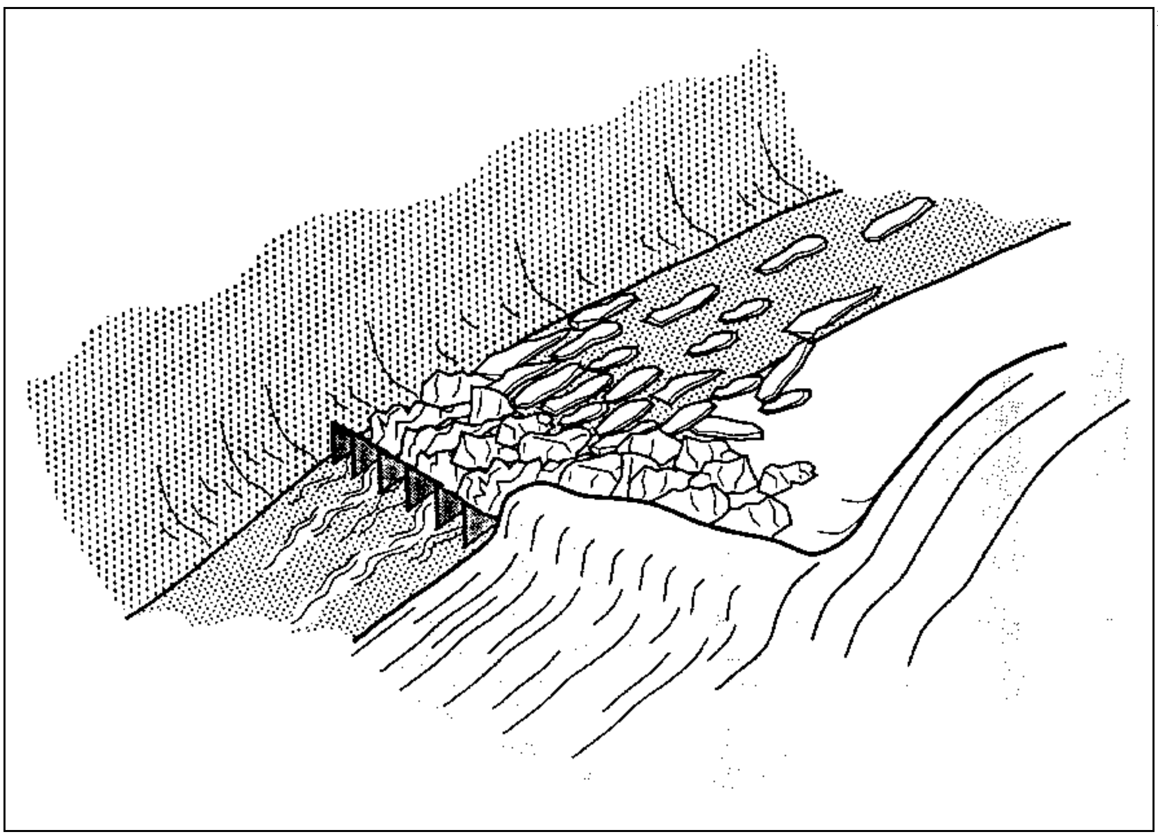
f. Creation of ice storage zones.

(1) Breakup ice jam frequency and flood levels can be reduced through storage of ice upstream from damage-prone areas in ice storage zone sites (Figure 4-7). Ice storage zones reduce the volume and/or rate of ice moving to a downstream jam location. By developing low overbank areas where ice can easily leave the channel during breakup, perhaps supplemented by dikes or booms to redirect ice movement, the volume of ice passing downstream can be substantially reduced. The ice left behind settles in side channels, the floodplain, or on the riverbanks.

(2) Ice storage zones can be designed to enhance natural jamming. Measures such as minor channelization, tree removal, bank regrading, berm construction, and installation of booms, piers, or other in-stream structures can be employed to initiate an ice jam at a location where ice storage will be maximized, damage will be minimal, and potential for failure and release of the jammed ice is low.

g. Thermal control.

(1) Thermal control of ice jams uses an existing source of warm water to melt or thin a downstream ice cover. Water, even a fraction of a degree above freezing, can be quite effective in melting ice over a period of days or weeks (Wuebben, Gagnon, and Deck 1992). External heat sources include cooling water effluent from thermal power plants, wastewater treatment plant effluent, and groundwater.



1

Figure 4-7. Schematic of ice storage zone combined with ice retention structure

The thermal reserve provided by water in nearby lakes and large reservoirs may also be a source of warm water for thermal control. Because water reaches its maximum density at a temperature of about 4 °C (39 °F), colder water in lakes tends to stratify above warmer water. An ice cover can form on the water surface even though the water at depth is still well above freezing. Warm water can be brought to the surface using air bubblers, pumps, or flow enhancers; or a low-level outlet in a dam may be used to release warm water.

(2) Warm water inputs can thin an ice cover prior to breakup so that it will not provide a jam initiation point. Warm water inputs can also reduce the volume of ice available to jam. Thermal control may be used to melt or thin an existing ice jam, thereby increasing the flow area within the jam and decreasing upstream water level.

h. Floodplain land use management and mapping.

(1) The best strategy for reducing flood losses is to keep people and property out of the floodplains. Proper land use planning would dramatically reduce the flood damage potential. This is particularly applicable in areas that experience chronic flooding.

(2) Floodplain mapping is essential for careful land use decision making. More than 20,000 communities have floodplain maps prepared by the National Flood Insurance Program. Since most flood insurance studies were prepared for open water flood events, ice jam flooding may not conform exactly to the regulatory or mapped floodplains. However, these maps remain useful tools for determining general floodplain boundaries and elevations.

i. Floodproofing.

(1) There are four basic types of floodproofing to minimize damage to individual structures during floods. These are: raising or relocation of a building, barrier construction, dry floodproofing, and wet floodproofing (Figure 4-8). Specific techniques of floodproofing are presented in the USACE manual on floodproofing (USACE 1991).

(2) Raising a building usually involves jacking it up and setting it on a new, higher foundation so that the inhabited areas and utilities are above predicted flood levels. Care must be taken that the new foundation can withstand the expected forces due to water flow and ice and debris loading. Sometimes this requires openings to allow flow through the new foundation. Relocation of the building to higher ground is quite effective but not always possible or acceptable.

(3) While raising and relocating a building are very effective methods of floodproofing, barrier construction can be equally effective in some cases. Barriers such as berms or floodwalls are constructed around the building to prevent floodwaters from reaching it. Openings in the barrier (for example, a driveway) should be avoided. Possible sources of flow through the barrier, such as seepage through the barrier and inflow from water or sewage lines, should be considered in barrier design.

(4) Dry floodproofing involves sealing the outside of the building to prevent floodwaters from entering. Dry floodproofing is usually only considered for cases where flood levels are less than a few feet above the base of the building because at higher levels, the pressure of the water (and ice) can collapse walls.

(5) Wet floodproofing allows the flood waters to enter a structure while at the same time minimizing damage by relocating utilities such as furnaces or hot water heaters above predicted high water levels. Wet floodproofing can be used where construction of barriers and dry floodproofing are not feasible.

4-3. Advance Measures

Mitigation measures put into place in anticipation of actual ice jam flooding are known as advance measures. These measures are used to reduce vulnerability to ice-jam-related flooding. Some emergency measures, such as ice removal, may also be initiated in advance of flooding.

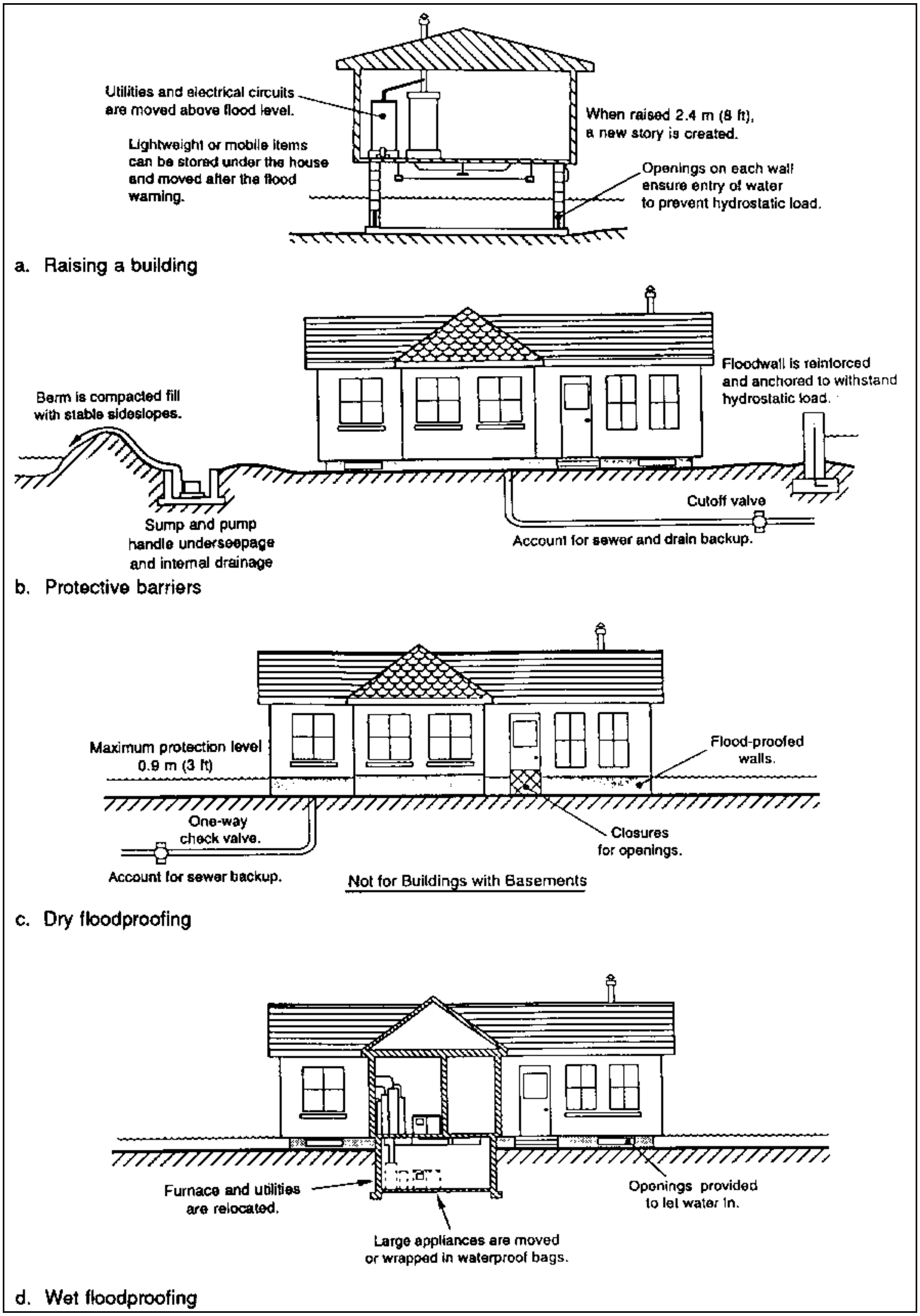


Figure 4-8. Floodproofing techniques (USACE 1991)

a. Forecasting. Because of the highly site-specific nature of ice jams, limited available data on ice jams, and the complexity of the hydrologic, meteorologic, and hydraulic processes involved in the formation of ice jams, forecasting ice jam flooding on a general level is not yet feasible. However, it is possible to analyze various ice jam parameters and develop a range of values that can be used to estimate the likelihood of a particular ice jam occurring under certain conditions (Wuebben, Gagnon, and Deck 1992). As more communities adopt flood detection systems, forecasting potential to reduce losses improves.

b. Monitoring and detection.

(1) The effects of ice jam flooding are often more localized than those of open water floods. Therefore, it is difficult to generalize ice jam data regionally. Since analytical techniques are less developed than those for open water floods, there is a stronger need for local historical data to serve as the basis for policy making.

(2) Simple remote gauges to collect data on river ice movement and breakup are useful. Water level gauges can detect any rapid increase in river stage, which often precedes ice breakup. Automated temperature sensors help to verify whether conditions are conducive to ice jam formation or breakup. Ice motion detectors (Zufelt 1993) can be imbedded in intact ice covers prior to breakup to give advance warning of the initiation of breakup upstream from a likely jam site (Figure 4-9). Existing gauges can be augmented with telemetry transmitters that send data directly to a local monitoring center or state and Federal agencies (e.g., National Weather Service or U.S. Geological Survey) by telephone, radio, or satellite.

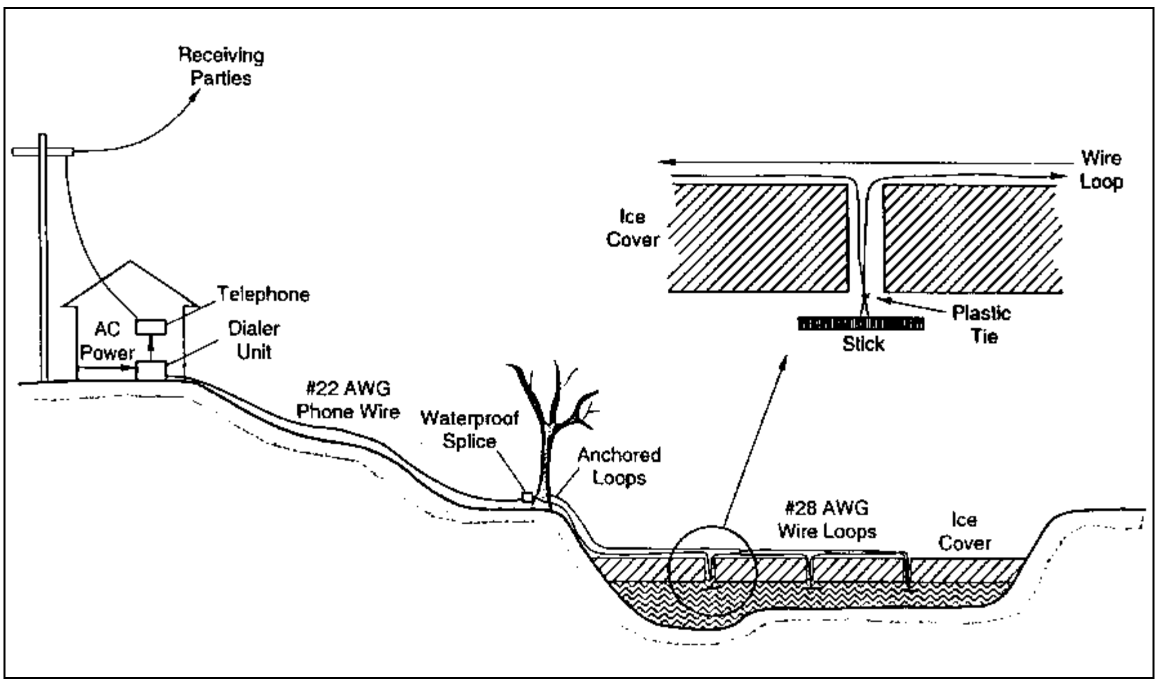


Figure 4-9. Schematic of ice motion detectors

An effective warning system must include a fully developed response system in addition to a detection system in order to save lives and reduce property damages.

c. Ice cutting.

(1) Mechanical or thermal ice cutting creates areas of weakness in an ice cover. This technique may be used to cause a stable ice sheet to break up earlier than normal, preventing it from acting as an obstruction to movement of upstream ice. On the other hand, ice cutting in selected locations can create a flow path for ice and water at breakup, reducing the probability of jamming.

Figure 4-10. Ice cutting

(2) Ice cutting (Figure 4-10) involves carving trenches in the ice either mechanically, using a chainsaw, a trenching machine, a back-hoe, or some other convenient device, or thermally, using a source of warm water or a substance that reacts chemically with the ice and melts it. The trenches can be partial or the full depth of the ice. They may follow the natural thalweg of the river channel, be cut along the edges of the channel to facilitate movement of the ice sheet, or be cut in a pattern designed to weaken the ice sheet. Ice cutting must be carefully timed to avoid refreezing the slots.

d. Revised operational procedures. Flow control may be available at dams or navigation structures located upstream or downstream from an ice jam problem site. The pool level can be raised or lowered to change the location of jamming in the river above the pool. Lowering the pool level early in the winter may expose some frazil ice production areas that would otherwise be covered. Lowering the pool after an ice cover has formed allows additional runoff storage before breakup. Discharge can be lowered at critical periods during ice formation to lower velocities and induce rapid and more extensive ice cover formation downstream. At breakup, lower discharge can decrease ice jam flooding or, in some cases, eliminate ice jam formation.

e. Dusting.

(1) Covering ice surfaces with a thin layer of dark material induces more rapid melting and ice weakening (Figure 4-11). Conventional materials include coal dust, fly ash, top soil, sand, and riverbed material. Initial tests with biodegradable materials such as leaves, mulch, and bark show promising results. This type of material is more easily spread than sand or coal dust by commercially available seeders and spreaders, but must be dry enough to flow freely for even distribution and to avoid freezing. Wind can be a problem, causing the fine materials to drift or snow to drift over the dust (Moor and Watson 1971).

(2) The dusting material is usually applied 2 to 3 weeks before breakup. The degree of melting depends on the quantity and material properties of the material deposited, solar radiation, and snowstorms. In areas where late snowstorms occur, several applications may be necessary. The melting period may be too short for significant reduction in ice volume or weakening if breakup occurs rapidly.

(3) The possible adverse environmental impacts of dusting materials must be considered prior to application.

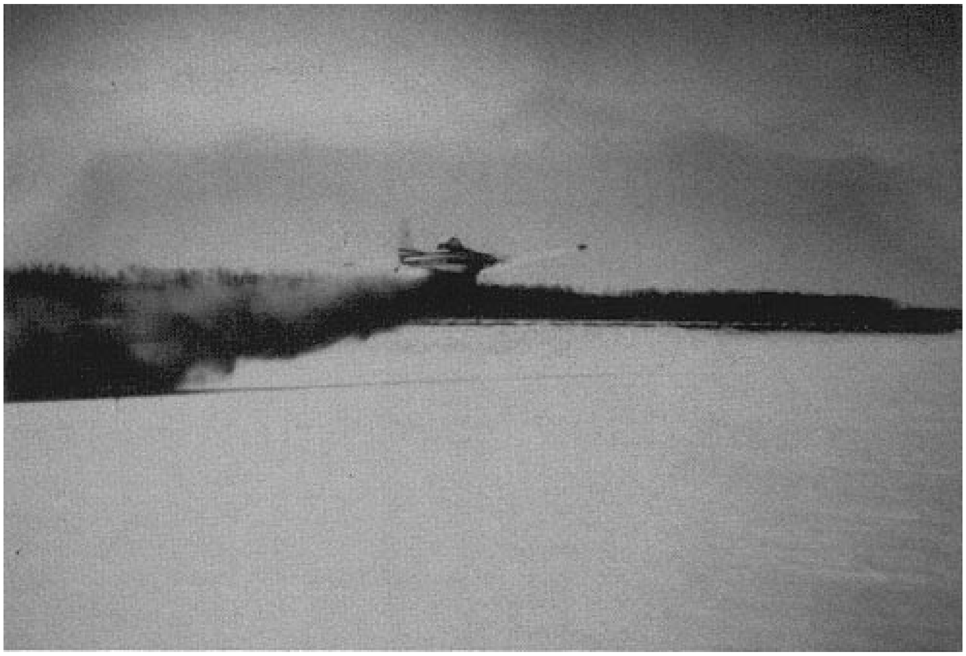


Figure 4-11. Ice dusting

4-4. Emergency Measures

a. Phases.

(1) Emergency measures are those taken after an ice jam has formed and flooding is imminent or already occurring. The effectiveness of emergency response may be reduced unless an emergency action plan exists that specifically refers to ice jams. Comprehensive emergency management includes four phases: preparedness, response, recovery, and mitigation. Emergency planners should have a clear line of command for multigovernmental management of ice jam flooding events. Plans should be tested in advance to be sure that all phases can be carried out and that all necessary materials and equipment are available when needed.

(2) Before implementing emergency measures, it is necessary to monitor the river ice conditions upstream as well as downstream from the jam site in order to select the best measures and to eliminate those that may only displace the flooding problem to another location. Early ice monitoring can also provide lead time to allow other emergency measures to be taken. For example, ice jam progression rate is important in freezeup ice jams, particularly when severe cold conditions conducive to rapid progression are forecast. For breakup jams, knowledge of the upstream ice thickness, extent, and relative strength is needed in estimating the remaining ice supply to the jam. The downstream ice conditions also need to be assessed, if only to determine whether or not there is sufficient open water area to receive ice when the jam releases.

(3) Ice jam emergency response measures include specific measures of ice breaking, mechanical ice removal, and ice blasting in addition to the traditional flood fighting efforts of evacuation, levee closing, and sandbagging, all of which qualify as advance measures.

b. Ice breaking.

(1) Ice covers can be broken prior to natural breakup using ice breaking vessels or construction equipment (Figure 4-12). Downstream movement of the broken ice should be enhanced to prevent localized breakup ice jams. Ice breaking is particularly useful to ease navigation in larger rivers and lakes.

Figure 4-12. Icebreaking vessel

(2) Reinforced lake tugs and river icebreakers are used to clear harbors and rivers, primarily in the Great Lakes system. However, icebreakers are expensive and cannot be used in small rivers of limited depth. Lack of availability on short notice and difficulty of access to the ice in upstream reaches can limit this method.

(3) On large rivers open to commercial navigation, towboats are used to break a channel through level ice or localized ice accumulations. The most powerful towboats available are needed for this purpose. Ideally, two or more towboats work in echelon (staggered, one behind and to the side of the other), with the largest towboat in the lead.

(4) Air cushion vehicles (ACV) can break large extents of relatively smooth sheet ice covers, usually in areas where the sheet ice may stop the ice run and initiate a jam. The advantages of an ACV are its speed and maneuverability and its ability to operate in shallow areas. Disadvantages are that it breaks the ice but does not move it, cannot operate over rough ice accumulations because of potential damages to its flexible skirts, and operation in cold weather can lead to severe icing of the propulsion system.

(5) Construction equipment can be used to break up an ice cover or an existing jam either from the shore or, if the ice is safe, from the river itself. It is generally best to begin at the downstream end of the ice cover and work upstream so the broken ice will be carried away. A heavy weight or wrecking ball can be dropped repeatedly on the ice surface to break up the ice (Figure 4-13). Ice can be broken either to form a channel or weaken the ice in specific locations.

c. Mechanical removal. Mechanical removal involves taking the ice out of the river and placing it elsewhere using bulldozers, backhoes, excavators, or draglines, starting from the downstream end of the ice accumulation (Figure 4-14). This approach is most effective on small streams because of the time required to excavate and additional safety concerns associated with wide or deep rivers. Mechanical removal can be expensive and slow but also quite effective. The lack of heavy equipment access to an ice-jam site is frequently an impediment to mechanical removal of ice.

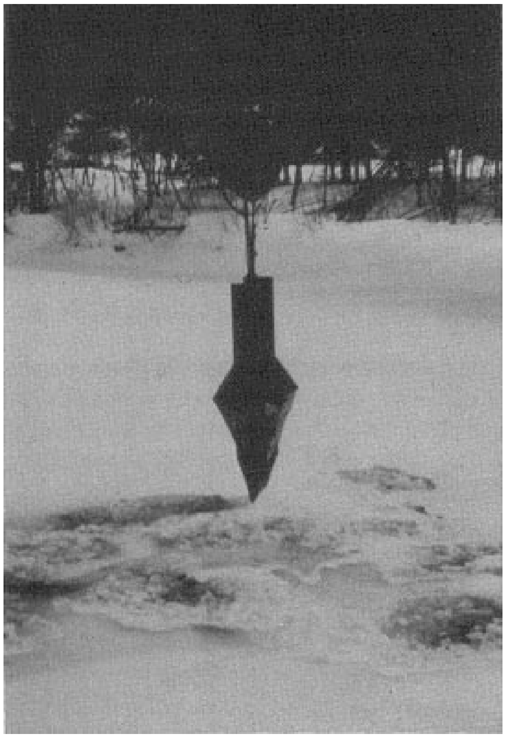


Figure 4-13. Ice breaking using a heavy wedge suspended from a crane

d. Ice blasting.

(1) A popular solution to ice jam problems, blasting breaks up an ice cover or loosens an ice jam so that it is free to move.

(2) Absolute prerequisites to successful blasting are that there be enough flow passing down the river to transport the ice away from the site and sufficient open water area exists downstream to receive the ice. Otherwise, the ice will simply rejam elsewhere and cause problems for another community. Blasting has been used to remove or weaken strong lake ice that initiated breakup jams at tributary-lake confluences or to create a relief channel within a grounded jam to pass water and decrease upstream water level. As for ice breaking and mechanical removal, it is recommended that blasting proceed upstream from the toe of the jam.

(3) While very dramatic, blasting is not a quick and easy solution. Blasting requires planning to locate and acquire the explosive, the equipment to drill holes, and the personnel. To be effective, the charge should be placed below the surface of the ice, which may be dangerous or impossible during an ice jam event. If the sheet ice or jam is stable, holes can be drilled at regular intervals from the surface to receive the charges. If not, the charges need to be dropped from a helicopter into existing openings in the ice cover.

(4) To blast from the top of the ice, certain procedures should be followed to maximize the degree of success. It is important that each charge be placed in the water immediately below the ice for the large gas bubble resulting from the blast to be most effective in breaking the ice. The charges should be weighted to sink but also roped to the ice surface so that they remain as close as possible to the ice underside and are prevented from being carried downstream by the current. As shown in Figure 4-15 (adapted from Mellor 1982), the diameter of the hole of the crater in the ice is primarily a function of charge weight and is relatively independent of ice thickness. For example, a charge size of about 18 kg (40 lb) will create a hole of 12 to 14 m (40 ft to 45 ft) in diameter for ice thickness ranging from 0.3 to 1.8 m (1 ft to 6 ft). Two more-or-less parallel rows of charges, set close enough so that the craters intersect, usually give the best results by creating a wide enough channel to preclude most secondary jamming. As much as possible, the thalweg of the river should be located and the blasting line placed along it.

(5) Although any kind of explosives can be used, experience has shown that ANFO works well. ANFO is a mixture of 6 percent (by weight) of fuel oil with prilled ammonium nitrate fertilizer, or approximately 0.0037 cu m (1 gal) of oil per 45.4 kg (100 lb) of fertilizer. The mixture must be detonated with a strong booster such as a stick of dynamite, TNT, or other special booster charges sold by powder companies. The ANFO charge must be kept dry, and it is recommended that it be placed in a plastic bag that can also hold the weight (such as a brick or sandbag) necessary to sink the charge. ANFO will dissolve with time if a misfire takes place. This will avoid leaving live charges on the river bottom. As a guide, it is preferable to use Primacord for all downhole and hookup lines. The charge is then set off with one electric cap that is taped to the Primacord at the last moment after the blasting party is off the ice (see Figure 4-16).

(6) Safety and environmental concerns must be addressed before implementation (USACE 1982). In particular, blasting in populated or developed areas may lead to damages to surrounding buildings from falling ice chunks. In general, blasting should be a last resort.

a. Using a dragline

b. With a backhoe

Figure 4-14. Ice removal

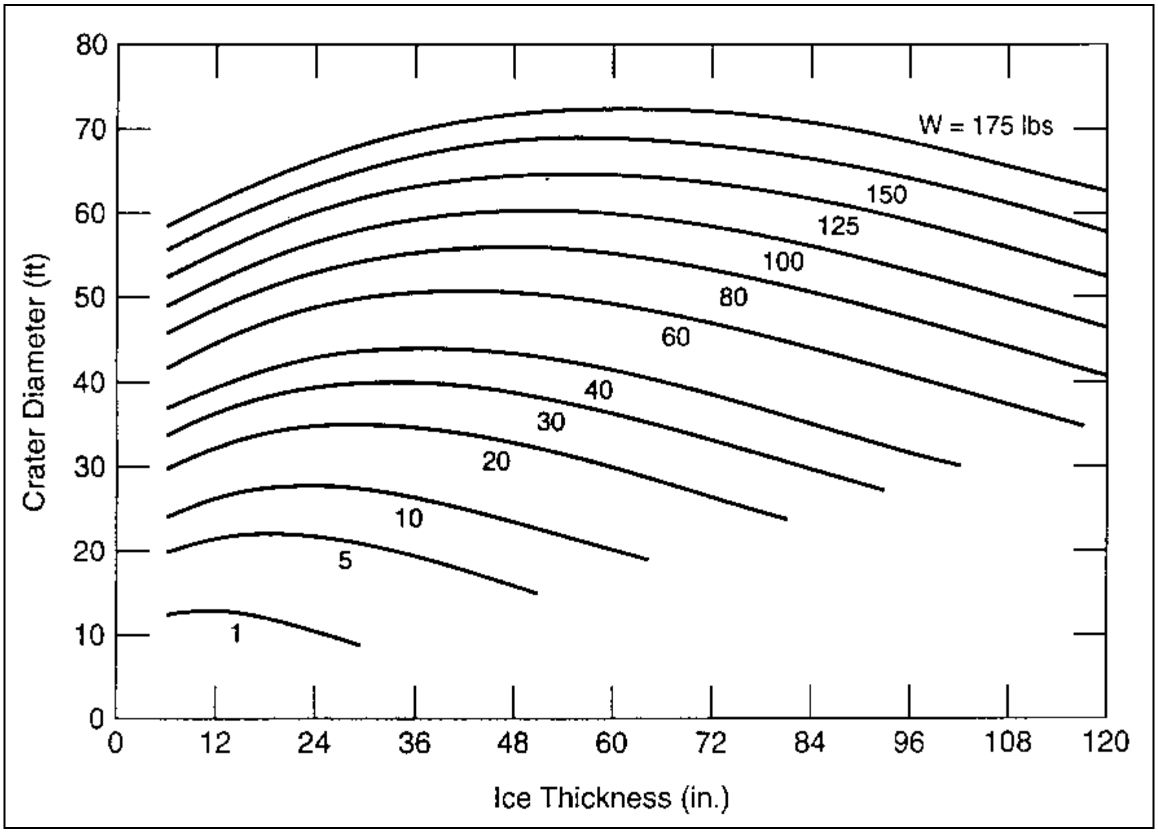


Figure 4-15. Crater hole diameter as a function of ice thickness and charge weight

Figure 4-16. Ice blasting

e. Evacuation. The principle behind evacuation is to move people at risk from a place of relative danger to a place of safety via a route that does not pose significant danger. Local law enforcement departments usually serve as lead organizations with standard operating procedures. Winter weather conditions should be taken into consideration when planning evacuation timing, equipment, and routes.

f. Levee closing. If ice jam flooding has been predicted, levees should be closed immediately and interior drainage pumps prepared for possible activation. Again, winter weather conditions that can hinder levee closing, such as snow drifts or frozen valves, should be identified. Monitoring water levels at levees may aid in the identification of possible overflow sites before serious damage can occur.

g. Sandbagging. Although ice can cause significant damage to sandbags used as protective barriers, the use of sandbagging as an emergency response measure can be very effective in reducing damages at particular facilities or locations. For example, sandbagging around sewage treatment plants or low points on roads or river banks can significantly reduce flood losses (see Figure 4-17).

a. To protect sewage treatment plant

b. To protext downtown buildings

Figure 4-17. Use of sandbags in Oil City, PA, in anticipation of ice jam flooding

Chapter 5
Ice Jam Mitigation Case Studies

5-1. Kankakee River, IL - Thermal Control

a. The upstream end of the backwater from the Dresden Island Lock and Dam on the Illinois River extends to about River Mile 3.5 on the Kankakee River near Wilmington, IL. Frazil ice floes form a stable ice cover on the pool, which thickens as frazil ice then deposits beneath the ice cover. The thick frazil ice deposit requires more force to break up than the thinner upstream ice and provides an obstruction to the passage of upstream river ice, which breaks up prior to this thick ice deposit. An ice jam often forms at the upper end of the deposit and progresses upstream, flooding the city of Wilmington and surrounding areas. The ice jam flood in 1982, which caused more than $8 million in damages, was followed by other ice jam events in 1984 ($500K) and 1985 ($1M). Several alternative ice jam mitigation measures were considered. Because of the proximity of the cooling pond for the Dresden nuclear power plant, thermal ice control appeared feasible. The intent of the thermal control was to thin or melt the thick frazil deposits that resist breakup, thus allowing the fragmented ice from upstream to pass unobstructed.

b. In a demonstration project, 20 °C (68 ^{o}F) water from the cooling ponds adjacent to the Kankakee River near Wilmington was siphoned in three 0.76-m-diam (30-in.-diam) pipes into the river upstream of the ice cover for 2 weeks prior to the anticipated breakup in 1988 (Figure 5-1). The maximum siphon flow is 4.25 cu m/s (150 cfs) compared with the expected river flow of approximately 113.2 cu m/s (4,000 cfs). The measured rise in water temperature was less than 1^{o}. The warm water input melted the existing ice so that ice floes passed unhindered during the natural breakup period and flooding was averted (Figure 5-2).

c. This $450,000 system worked successfully for 2 consecutive years. There were no reported negative environmental impacts.

5-2. Hardwick, VT - Improved Natural Storage, Ice Retention, Mechanical Removal

a. Relatively frequent breakup ice jams have caused serious damage in this small Vermont town. A combination of techniques is used to reduce flooding impacts.

b. To slow the movement of broken ice, two booms were constructed (Figure 5-3). The vertically oriented tire booms, which are suspended from shore, collect broken ice during breakup, some of which is stored on the overbanks. The booms delay the downstream passage of ice while ice removal is performed in town. Since the winter of l983-84, these booms have been placed upstream from town annually. Although the booms occasionally fail, they do provide ice retention.

c. An ice storage area downstream of the town accommodates some of the ice that jams and thereby provides added protection. In addition, when local officials first begin to notice serious ice jams developing, the town road crew mechanically breaks up and removes the ice to keep the river open.

5-3. Oil City, PA - Floating Ice Boom, Revised Operational Procedures, Ice Control Dam

a. Oil City is located in northwestern Pennsylvania. The city suffered chronic ice jam flooding from the mid-1880s to the mid-1980s. In February 1982, ice jam flooding caused more than $4 million in damages in downtown Oil City.

b. Research indicates that the ice jam flooding was caused in part by a massive deposit of frazil ice naturally occurring in a long, deep pool in the Allegheny River downstream of Oil City and extending upstream past the confluence with Oil Creek. Large quantities of frazil generated in the creek were also deposited in the river and backwater at the mouth of the creek. The ice on Oil Creek typically broke up and moved downstream before the ice cover on the Allegheny River. The tributary ice ran unimpeded to the river until it met the stable ice at the confluence with the Allegheny River and formed an ice jam.

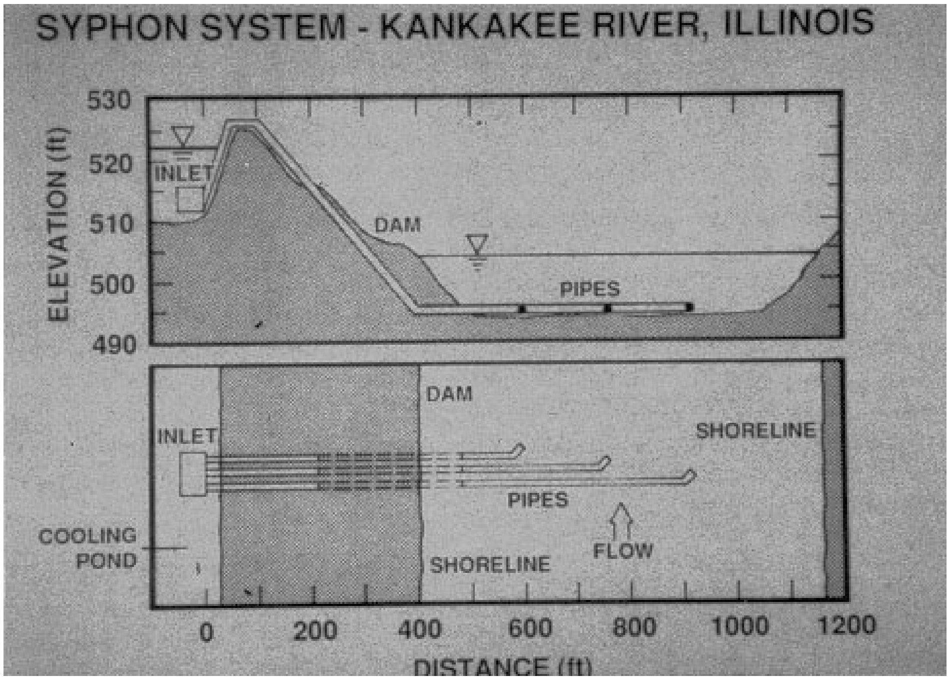


Figure 5-1. Schematic of siphon system, Kankakee River, IL

Figure 5-2. Map of meltout

c. An environmentally and economically beneficial floating structure (Figure 5-4) was designed and installed upstream of the city on the Allegheny River to quickly form a stable ice cover to suppress further frazil generation and minimize excessive deposition in the trouble area. Discharge at an upstream dam was decreased during freezeup to allow the rapid formation of a stable ice cover at the boom. The floating boom was installed during the 1982-83 winter at a

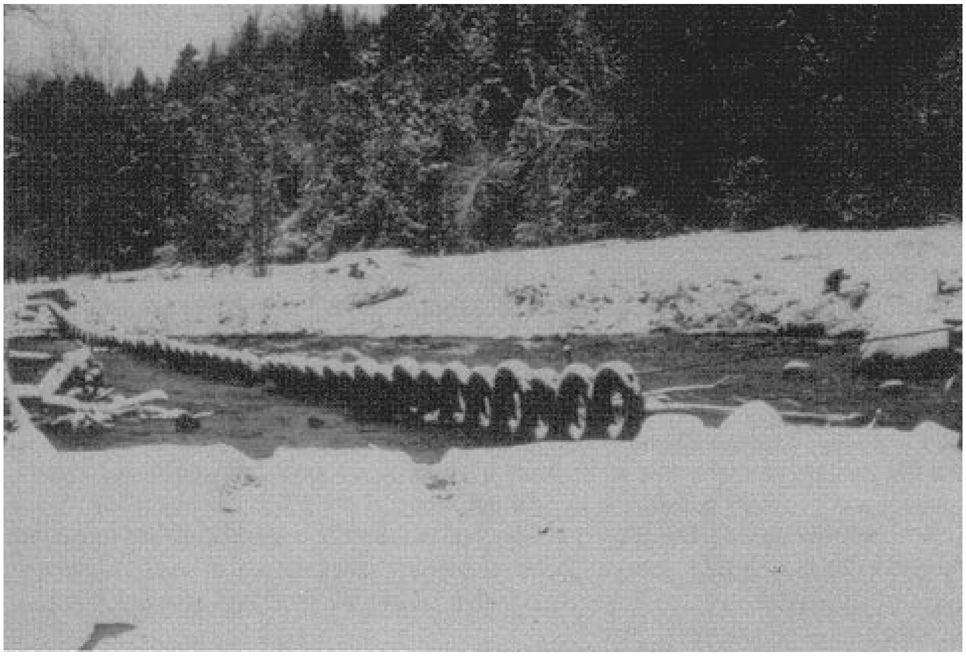


Figure 5-3. Tire boom at Hardwick, VT

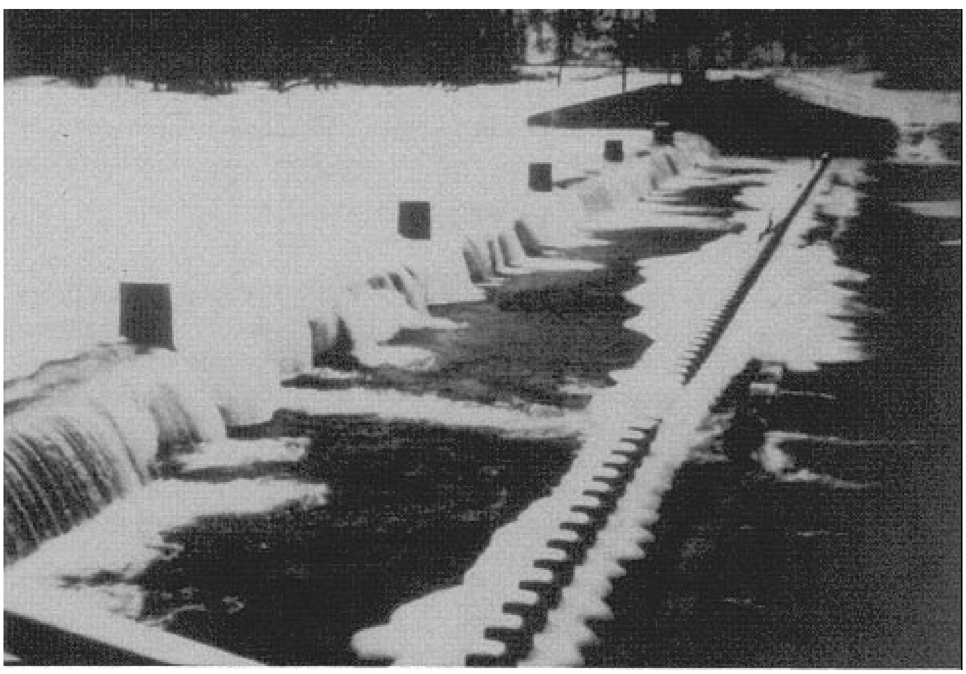


Figure 5-4. Oil Creek structure, Oil City, PA

cost of $900,000, for a unit cost of about $1,700/ft. Since its installation, the boom has been fully effective and the river has remained relatively ice-free downstream from the boom in spite of extremely cold winters (Deck 1984).

d. A permanent ice control structure was also constructed on Oil Creek by the Pittsburgh district of the Corps of Engineers in 1989. The structure is 1.5 m (5 ft) high, 107 m (351 ft) long, and includes a 13.7-m-wide (45-ft-wide) leaf gate, which allows for sediment and fish passage as well as recreational use by canoeists and fishermen. Two low-flow pipes also provide fish passage. Levees were constructed on both upstream banks to contain the Standard Project Flood. The project cost was $2.2 million for a unit cost of approximately $6,300/ft (Wuebben, Gagnon, and Deck 1992). No damaging ice jam has occurred in Oil City since the Allegheny River ice boom and Oil Creek ice control structure were put into use.

5-4. Lancaster, NH - Weir, Ice Retention, Storage

a. Lancaster experienced ice jams every year due to breakup of the ice cover on the Israel River. Broken ice passage is impeded by a natural frazil deposit that forms at the change in slope, which occurs at the upper end of the backwater formed by the confluence with the Connecticut River. Few ice jams were reported prior to 1936, probably because four dams that have been removed since that time decreased frazil production, provided frazil ice storage, decreased the downstream transport of frazil ice, and delayed the downstream passage of broken ice.

b. The Corps' New England Division and Cold Regions Research and Engineering Laboratory (CRREL) designed and built an ice control project to reduce the production and transport of frazil ice and decrease the volume of ice available to ice jams downstream. Environmental and financial constraints limited the scope of the project, which ideally would have provided the same protection as the four dams. The project consists of two parts: a submarine net to capture surface ice and a 36.6-m-long by 2.7-m-high (120-ft-long by 9-ft-high) permanent weir located several miles downstream (Figure 5-5). The submarine net is a form of suspended ice retention structure that allows water to flow through but captures floating ice pieces, which are then stored in overbank flood plains.

c. The ice control weir includes four 1.2-m-wide by 2.4-m-deep (4-ft-wide by 8-ft-deep) sluiceways for fish passage. During the winter, stop logs or metal bar racks are placed in the sluiceways to develop an ice retention pool. The pool forms an ice cover, and frazil ice generated upstream deposits beneath the ice cover. After the ice cover has formed, two of the gates are opened, allowing the pool level to drop. This creates additional water storage in the pool area, provides additional discharge capacity through the weir, and slightly delays the breakup and movement of ice through the pool as well. The project, which cost $300,000 (approximately $1,800/ft) was completed in 1982. Although costs constrained the size of the project to less than ideal, no major flooding has occurred since this relatively inexpensive, innovative project was constructed (Axelson 1991).

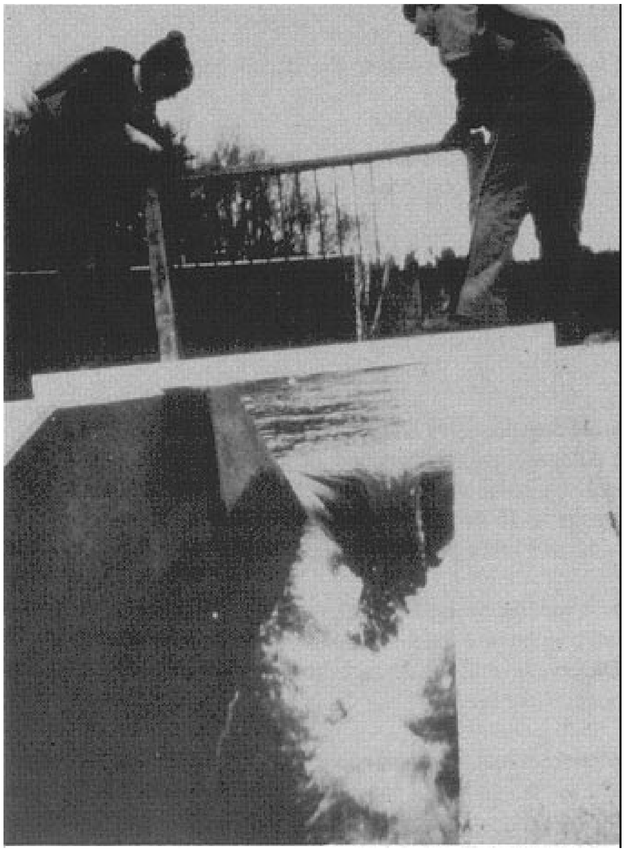
5-5. Idaho Falls, ID - Land Acquisition

In 1982, two hydroelectric dams were removed and rebuilt on the Snake River near Idaho Falls. Freezeup ice jam floods on the Snake River affected Bear Island homeowners during the winters of 1982-83 and 1984-85. Ice jam floods also threatened two houses on the west bank of the river. The homeowners associated their flooding problems with the rebuilt dams located 9.6 km (6 miles) downstream. As a result, they requested help from the city of Idaho Falls, the Federal Energy Regulatory Commission, and elected officials. Field data collection and hydraulic analyses indicated that ice jams were caused by frazil produced in turbulent open water sections of the Snake River. The results showed that the changes in reservoir levels and the dams had no direct effect on ice jam flood levels in one area, although two properties were affected by changes in reservoir levels. Based on CRREL's recommendations, the City of Idaho Falls decided to purchase the two properties affected by the Upper Power Project (Zufelt, Earickson, and Cunningham 1990).

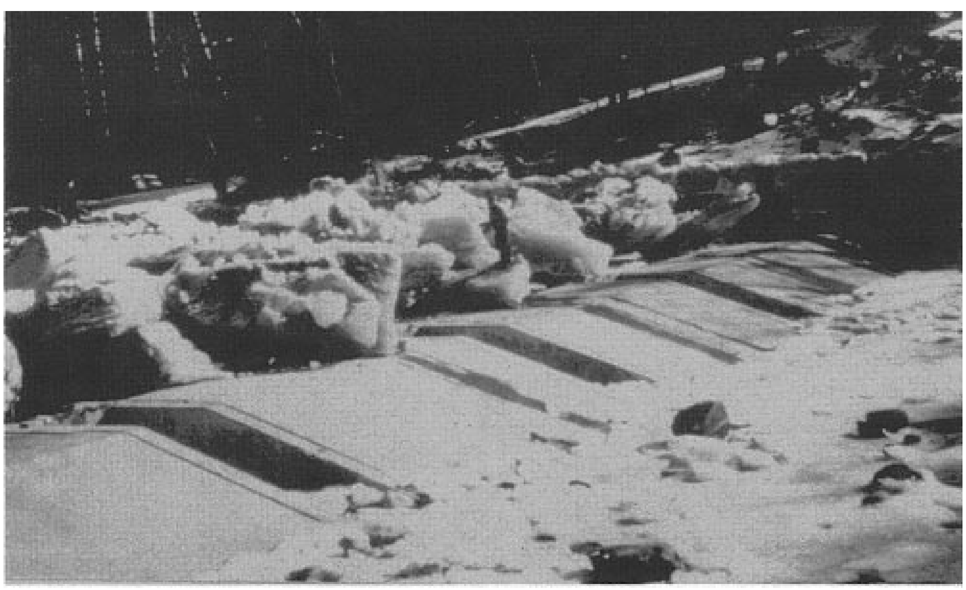
5-6. Platte River, NE - Dusting

a. In February 1978, disastrous ice jam flooding took place on the Platte River in Nebraska, causing millions of dollars in damages. Record cold temperatures in January 1979 produced both extremely thick ice on the Platte River and its tributaries and a consequent threat of similar ice jams during spring breakup. Ice dusting, approximately 3 weeks before breakup, was recommended for alleviating ice jam floods.

b. The Nebraska Civil Defense agency decided to try dusting selected areas with technical assistance from the Corps. The Corps assisted with advance preparation for the ice dusting operation during the actual dusting procedures to ensure a



a. Installing racks in sluiceways



b. View of structure in early spring

Figure 5-5. Lancaster, NH, weir

proper application rate on the test areas, and during subsequent measurement to evaluate the effectiveness of the program. Dusting was performed using coal ash and slag from a local power plant.

c. Two periods of breakup occurred in March 1979. Because the dusted ice had already started to deteriorate, the jams were minor, even following heavy rains. The ice and water flowed smoothly down the channel with no flood damages (USACE 1979).

d. Similar dusting operations were repeated in March 1994, prompted by severe ice jam flooding in the spring of 1993 that threatened the water wells supplying the city of Lincoln, NE (USACE 1994).

5-7. Allagash, ME - Floodproofing, Relocation

a. Rainfall and 5 to 6 days of mild temperatures resulted in breakup ice jams and severe flooding on the St. John, Little Black, Allagash, and Aroostook Rivers in April 1991. In Allagash, two bridges and 11 homes on the St. John River were destroyed. Twenty-two other homes suffered damages. A 304.8-m (1,000-ft) section of a state highway was washed away. Ice jam flooding also caused evacuations and damage to 16 homes in neighboring towns. Damages totaled more than $14 million, mostly for rebuilding bridges, roads, and other public works (FEMA 1991).

b. Raising the affected buildings was considered. However, it was determined that elevation of the ground floor of homes to meet the requirements of the National Flood Insurance Program and local floodplain regulations might not provide adequate protection from future ice jams. In the town of Dickey, several residents indicated a willingness to relocate outside the floodplain. The following permanent settlement changes were made:

(1) Three new homes were built at higher elevations on the original lots, and one home was repaired and moved to higher ground on the same lot.

(2) Two new homes were constructed on new sites outside the floodplain, three homes were repaired and were moved to higher ground outside the floodplain, and two destroyed homes were replaced with mobile homes on higher sites.

(3) Thirteen wells and/or septic systems were replaced with mitigation measures, meaning they were floodproofed or moved to higher ground.

Chapter 6
Ice Jam Mitigation Assistance

a. In most instances, the lead agency in ice jam mitigation is the U.S. Army Corps of Engineers. Other Federal agencies involved in ice jam mitigation include FEMA, the U.S. Geological Survey, and the Bureau of Reclamation.

b. At the state level, many agencies play important roles in helping to reduce the threat of, prepare for, or clean up after flooding, including environmental conservation agencies, disaster services agencies, and/or transportation departments.

c. At the local level, county and city governments, as well as schools, utility companies, private relief organizations, private businesses, and individuals all participate in ice jam mitigation efforts.

d. An excellent overview of emergency management techniques has been prepared by the International City Management Association. *Emergency Management: Principles and Practice for Local Governments* (Drake and Hoetmer 1991) provides an accessible foundation in the principles of emergency management that would be useful for ice jam mitigation as well as other natural hazards. Other free public awareness, preparedness, mitigation, and floodproofing materials can be found in the reference list.

6-1. U.S. Army Corps of Engineers

As the agency responsible for most of the nation's river management, USACE plays a major role in ice jam mitigation efforts. In cooperation with local authorities, the Corps has designed and built levees, flood control dams, and ice control structures, as well as participated in emergency response to ice jams. A recent survey (White 1992) shows that Corps districts have implemented a wide variety of effective strategies in rivers around the country, including ice jam removal, evacuation, sand bagging, and technical advice.

6-2. Cold Regions Research and Engineering Laboratory

a. One of four research laboratories operated by USACE, CRREL specializes in problems associated with cold regions. The CRREL Ice Engineering Research Branch is involved in research that increases knowledge of the causes of ice jams and methods that can be used effectively to reduce the occurrence and effects of ice jams.

b. Any Corps district office can contact CRREL to monitor and study an ice jam problem area or help develop an innovative project to reduce ice jam flooding potential.

6-3. Ice Jam Database

a. With the help of individuals and agencies involved in ice jam mitigation, CRREL has developed an ice jam database. More than 7,000 ice jam events are included. The database includes existing knowledge of the strategies used by the Corps district offices and others to deal with ice jams around the country (Figure 6-1).

b. Specifically, the database informs an emergency manager whether or not a particular river has ice jam potential, or which measures have been used successfully to reduce damages in previous ice jam situations. The database covers:

- River name.
- Date of ice jam(s).
- Nearest towns and state.
- Type of ice jam(s).

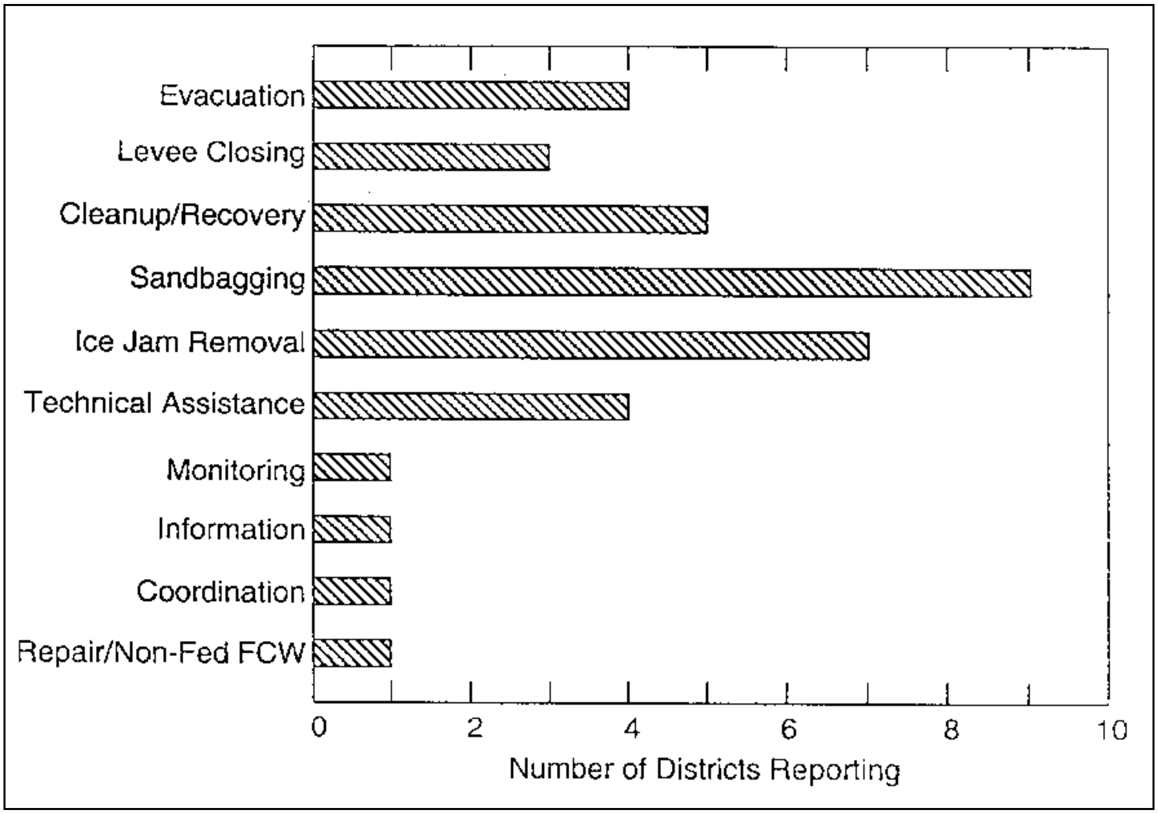


Figure 6-1. Emergency response measures reported by districts (White 1992)

- Extent of damages.
- Points of contacts.
- Publications (if available).
- Information, if available, on whether the ice jam can be classified as a freezeup, midwinter, breakup, or combination jam.
- The range of ice jam mitigation design measures attempted.
- The efficacy of any emergency response methods used in the past.

c. The database is available to PC users on either 3.5-in. or 5.25-in. floppy disks and allows users to browse; sort by river, state, or year of event; and print database entries.

d. For more information on the ice jam database, contact the Ice Engineering Research Branch at CRREL by phone at (603) 646-4378 or fax (603) 646-4477.

Appendix A
References

Ashton, G., ed. (1986). *River and lake ice engineering*, Water Resources Publications, Littleton, CO.

Axelson, K. D. (1991). "Israel River ice control structure." *Inspiration: Come to the Headwaters*. Proceedings of the Association of State Floodplain Managers, 10-14 June, Denver, CO.

Deck, D. (1984). "Controlling river ice to alleviate ice jam flooding." *Proceedings of the Conference on Water for Resource Development*. HY Div/ASCE, 14-17 August, Coeur d'Alene, ID.

Drabek, T. E., and Hoetmer, G. J., eds. (1991). *Emergency management: Principles and practice for local governments*. International City Management Association, Washington, DC.

Elhadi, N. E., and Lockhart, J. G., eds. (1989). *New Brunswick river ice manual*, New Brunswick Subcommittee on River Ice, Environment Canada Inland Waters Directorate, Fredericton, New Brunswick.

Federal Emergency Management Agency. (1989). *Flood studies and surveys; Historical statistics* (as of September 30, 1989). Unpublished.

Federal Emergency Management Agency. (1991). *Hazard mitigation survey hazard team report, Maine*, FEMA-901-DR-ME, Boston, MA.

Federal Emergency Management Agency. (1992a). *Floodplain management in the United States: An assessment report*, FIA-18, Boston, MA.

Federal Emergency Management Agency. (1992b). *Interagency hazard mitigation team report (Montpelier, VT)*, FRMA-938-DR-VT, Boston, MA.

International Association for Hydraulic Research. (1986). "River ice jams: A state-of-the-art report." *Proceedings, IAHR Symposium on Ice*, Iowa City, IA, 561-594.

Mellor, M. (1982). "Breaking ice with explosives," Report 82-40, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH.

Moor, J. H., and Watson, C. H. (1971). "Field tests of ice prevention techniques," *Journal of the Hydraulics Division, American Society of Civil Engineers* 92(HY6), 777-789.

Urroz, G. E., and Ettema, R. (1994). "Application of two-layer hypothesis to fully developed flow in ice-covered curved channels," *Canadian J. of Civil Engineering* 21(1), 101-110.

U.S. Army Corps of Engineers. (1981). *RIM - River Ice Management*, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH.

U.S. Army Corps of Engineers. (1982). "Ice engineering," Engineer Manual 1110-2-1612, Washington, DC.

U.S. Army Corps of Engineers. (1990). "Winter navigation on inland waterways," Engineer Manual 1110-8-1(FR), Washington, DC.

U.S. Army Corps of Engineers. (1991). *Flood proofing techniques, programs and references*, Report of the National Flood Proofing Committee, prepared by Dewberry and Davis with French and Associates, Ltd.

U.S. Army Corps of Engineers. (1993, 1994). *Annual flood damage report to Congress*, Washington, DC.

U.S. Army Engineer District, Omaha. (1979). *Ice dusting of the Platte River, 1979*. Omaha, NE.

U.S. Army Engineer District, Omaha. (1994). "Lower Platte River ice flooding interim report," Section 22, Omaha, NE.

U.S. Army Engineer Division, New England. (1980). *Section 206: Flood plain management assistance historical ice jam flooding in Maine, New Hampshire and Vermont*. Waltham, MA.

White, K. D. (1992). "Ice jam statistics recorded on data base," Ice Engineering Bulletin Note No. 2, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH.

White, K. D., and Zufelt, J. E. (1994). "Ice jam data collection," Special Report 94-7, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH.

Wuebben, J. L., Gagnon, J. J., and Deck, D. S. (1992). "Ice jam flood assessment for the Buford-Trenton Irrigation District and vicinity, Williston, North Dakota," Project Report, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH.

Zufelt, J. E. (1993). "Ice motion detector system," Ice Engineering Bulletin No. 4, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH.

Zufelt, J. E, Earickson, J. A., and Cunningham, L. (1990). "Ice jam analysis at Idaho Falls, Snake River, Idaho," Special Report 90-43, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH.

Appendix B
Glossary

[Extracted from the U.S. Army Corps of Engineers (1990) and International Association for Hydraulic Research (1986).]

Anchor ice. Frazil ice attached or anchored to the river bottom, irrespective of the nature of its formation.

Beginning of breakup. Date of definite breaking, movement, or melting of ice cover or significant rise of water level.

Beginning of freezeup. Date on which ice forming a stable winter ice cover is first observed on the water surface.

Border ice. An ice sheet in the form of a long border attached to the bank or shore; shore ice.

Breakup. Disintegration of ice cover.

Breakup date. Date on which a body of water is first observed to be entirely clear of ice and remains clear thereafter.

Breakup jam. Ice jam that occurs as a result of the accumulation of broken ice pieces.

Breakup period. Period of disintegration of an ice cover.

cfs. Cubic feet per second, a measure of flow.

Channelization. Modification of a natural river channel; may include deepening, widening, or straightening.

Conveyance. A measure of the carrying capacity of the river channel.

Floc. A cluster of frazil particles.

Floe. An accumulation of frazil flocs (also known as a “pan”) or a single piece of broken ice.

Floodplain. Land area adjoining a water body that is not normally submerged but may be submerged during flood conditions.

Frazil. Fine spicules, plates, or discoids of ice suspended in water. In rivers and lakes, frazil is formed in supercooled, turbulent water.

Frazil slush. An agglomerate of loosely packed frazil that floats or accumulates under an ice cover.

Freezeup date. Date on which the water body was first observed to be completely frozen over.

Freezeup jam. Ice jam formed as frazil ice accumulates and thickens.

Gorge. In the past, ice jams were sometimes referred to as “ice gorges.”

Grounded ice. Ice that has run aground or is in contact with ground underneath it.

Hanging (ice) dam. A mass of ice composed mainly of frazil or broken ice deposited underneath an ice cover in a region of low flow velocity.

Hummock. A hillock of broken ice that has been forced up by pressure.

Ice arch. Frazil or fragmented ice that has stopped moving and bridges across a river channel; also called an “ice bridge.”

Ice jam. A stationary accumulation of fragmented ice or frazil that restricts or blocks a stream channel. The term “ice gorge” is also used in some areas.

Overbank flow. Flow that exceeds the level of the river's banks and extends into the floodplain.

Riprap. Rocks strategically placed against riverbanks or beds to prevent erosion of underlying material.

Sheet ice. A smooth, continuous ice cover formed by in situ freezing (lake ice) or by the arrest and juxtaposition of ice floes in a single layer.

Supercooled water. Water whose temperature is slightly below the freezing point (32 ^{o}F or 0 ^{o}C).

Thalweg. Deepest portion of the river channel; the line of major flow.

Water slope. Change in water surface elevation per unit distance.

Water stage. The water surface elevation above the bottom of the river channel.

Weir. Barrier placed in a river to raise water elevation.